DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

STATIC STABILITY CHARACTERISTICS OF A SYSTEMATIC SERIES OF STERN CONTROL SURFACES ON A BODY OF REVOLUTION

by

Elizabeth M. Dempsey

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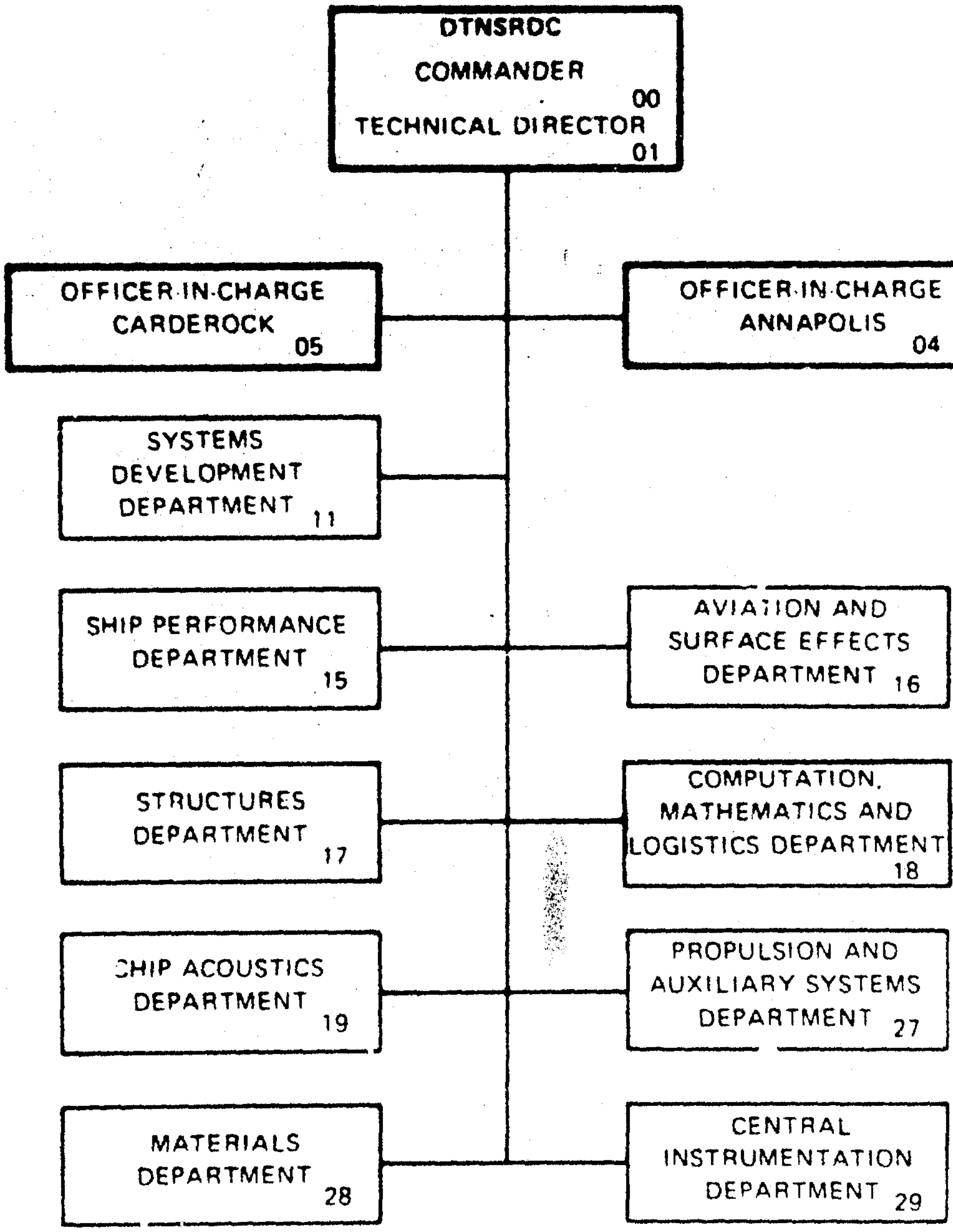

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Experiments were conducted to determine the forces and moments due to angle of attack on a representative streamlined body of revolution alternately appended with members of a systematic series of stern control surfaces. The data from these experiments are presented in the report in the form of graphs and tabulations of the nondimensional force and moment coefficients and static stability derivatives. Based on these data empirical mathematical expressions have been developed to predict the contribution of stern-

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planes to the static stability derivative Z_w' when the sternplanes are appended to a submarine whose basic hull is a streamlined body of revolution. A graph is presented for estimating the location of the center of pressure of the forces due to the presence of sternplanes.

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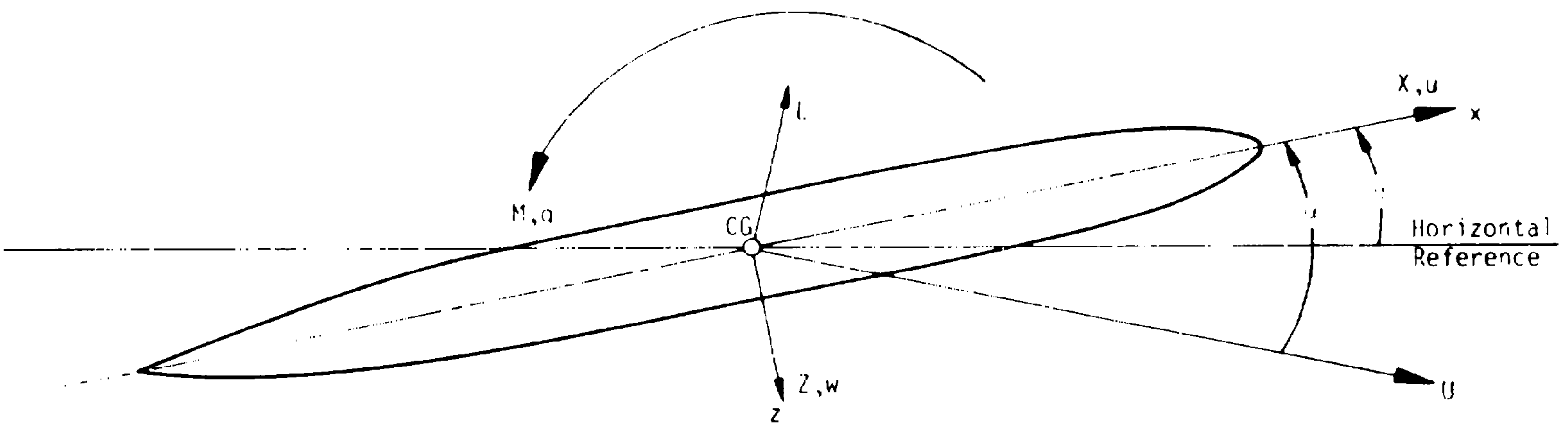
NOTATION

A		Projected area of one sternplane extended to hull centerline (leading edge continued at same angle)
AP		Aft perpendicular (end of afterbody)
a		Effective aspect ratio, $\frac{2b^2}{A}$
b		Distance between sternplane tip chord and hull centerline
$\frac{2b}{d}$		Span parameter
C_L		Lift coefficient, $\frac{L}{\frac{1}{2}\rho(2A)U^2}$
$\bar{c}$		Mean chord of sternplane, average of tip chord and root chord
d		Maximum diameter of hull
L		Hydrodynamic lift force, positive upward
ℓ		Length of hull
M	$M' = \frac{M}{\frac{1}{2}\rho\ell^3U^2}$	Hydrodynamic moment about y-axis
M_w	$M_w' = \frac{M_w}{\frac{1}{2}\rho\ell^3U}$	Derivative of moment component with respect to velocity component w
ΔM_w	$\Delta M_w' = \frac{\Delta M_w}{\frac{1}{2}\rho\ell^3U}$	Contribution of sternplanes to M_w'
U		Velocity of origin of body axes relative to fluid
w	$w' = \frac{w}{U}$	Component of U along z-axis
X	$X' = \frac{X}{\frac{1}{2}\rho\ell^2U^2}$	Hydrodynamic longitudinal force, positive forward
Z	$Z' = \frac{Z}{\frac{1}{2}\rho\ell^2U^2}$	Hydrodynamic normal force, positive downward

Z_w	$Z_w' = \dfrac{Z_w}{\frac{1}{2}\rho \ell^2 U}$	Derivative of normal force component with respect to velocity component w
ΔZ_w	$\Delta Z_w' = \dfrac{\Delta Z_w}{\frac{1}{2}\rho \ell^2 U}$	Contribution of sternplanes to Z_w'
α		Angle of attack
ρ		Mass density of water



Sketch Showing Positive Directions of Axes, Angles, Velocities, Forces, and Moments

x

ABSTRACT

Experiments were conducted to determine the forces and moments due to angle of attack on a representative streamlined body of revolution alternately appended with members of a systematic series of stern control surfaces. The data from these experiments are presented in the report in the form of graphs and tabulations of the nondimensional force and moment coefficients and static stability derivatives. Based on these data empirical mathematical expressions have been developed to predict the contribution of sternplanes to the static stability derivative Z_w' when the sternplanes are appended to a submarine whose basic hull is a streamlined body of revolution. A graph is presented for estimating the location of the center of pressure of the forces due to the presence of sternplanes.

ADMINISTRATIVE INFORMATION

This project was performed under the sponsorship of the General Hydrodynamic Research Program.

INTRODUCTION

An experimental investigation was made of the static stability characteristics of a streamlined body of revolution alternately appended with each set of a family of low-aspect-ratio stern control surfaces. The purpose of the investigation was to determine the contributions of the control surfaces to the forces and moments on the total fin-body combinations and to present the results in a form that would be useful in the preliminary design of submarines from a stability point of view.

In the past extensive experimental work was carried out at the David W. Taylor Naval Ship R&D Center to determine the free-stream

characteristics of a family of low-aspect-ratio control surfaces.[1] This effort provided comprehensive information more directly applicable to submarine appendage design than had been available in the aerodynamic literature. As a next step, the work presented in this report was performed to provide fundamental data on the characteristics of control surfaces when fin-body interaction factors are present.

This report describes the model and stern control surfaces; outlines the procedures used in the experiments; presents graphs and tables of the experimental results; and present empirical methods for estimating the contributions of sternplanes to the static stability derivatives for submarines whose basic hulls are streamlined bodies of revolution.

GENERAL CONSIDERATIONS

The hulls of most modern submarines are basically bodies of revolution with afterbodies (the portion of the body aft of the maximum diameter) such that the ratio of the length of the tail (or afterbody) to the maximum diameter falls somewhere between 4.2 and 4.6. This characteristic is a rough indication that the fullness of the tails and the nondimensional thickness of the boundary layers in the vicinity of the stern control surfaces do not vary markedly from submarine to submarine.

For this reason the assumption was made that an experimental study of fin-body combinations composed of stern control surfaces mounted on a body of revolution having a fairly representative tail section would yield fin-body interaction effects that could be applied to other bodies having generally similar afterbodies regardless of the shape of the forebodies.

[1] Whicker, L. Folger and Leo F. Fehlner, "Free-Stream Characteristics of a Family of Low-Aspect-Ratio, All-Movable Control Surfaces for Application to Ship Design," DTMB Report 933 Revised Edition (December 1958).

An existing streamlined body of revolution having an afterbody fineness ratio of 4.4 was chosen as the test vehicle. A family of 20 sets (4 identical stern control surfaces per set) was selected which covered a range of sizes, relative to the hull, that could reasonably be expected to be of interest for submarine design. No propeller was used.

The planform of the planes was such that the trailing edges were normal to the tip chords. The sweep angle and section shape were the same for all. The spans and tip chords were varied in a systematic way so that for each of four outreaches from the centerline of the model there were five sets of planes with different tip chords.

The vehicle was tested with each of the 20 sets of planes oriented on the hull in the cruciform arrangement with trailing edges normal to the longitudinal axis of the hull. The rudders were located slightly forward of the sternplanes and the longitudinal positions of the trailing edges of both sternplanes and rudders with respect to the AP of the model remained the same for all configurations.

DESCRIPTION OF BODY AND STERN CONTROL SURFACES

The body was Model 4621, a 180-inch (4.572-metre) streamlined body of revolution with a 24.52-inch (0.623-metre) maximum diameter. The hull was fiberglass with a mahogany tail cone. The offsets of the model and other pertinent characteristics are given in Tables 1a and 1b.

The control surfaces were constructed of mahogany and consisted of a family of 20 sets of 4 identical square-tipped planes. The trailing edge of each of the planes was normal to the tip chord. Each had a quarter-chord sweep angle of 15.25 degrees and a NACA 0015 section shape. The bases of the planes were cut on a 12-degree slant to fit the average

TABLE 1A - GEOMETRIC CHARACTERISTICS OF BARE HULL EXPRESSED IN U.S. CUSTOMARY UNITS

Length, ft.	15.0
Maximum diameter, ft.	2.044
Wetted surface area, sq. ft.	70.55
Volume, cu. ft.	29.53
Longitudinal center of buoyancy, ft.	6.684

Hull Offsets

X in inches	Y in inches	X in inches	Y in inches
0.0	0.000	93.6	11.82
3.6	3.500	97.2	11.66
7.2	4.977	100.8	11.49
10.8	6.108	104.4	11.29
14.4	7.047	108.0	11.07
18.0	7.850	111.6	10.83
21.6	8.549	115.2	10.56
25.2	9.160	118.8	10.27
28.8	9.697	122.4	9.954
32.4	10.17	126.0	9.613
36.0	10.58	129.6	9.243
39.6	10.93	133.2	8.843
43.2	11.24	136.8	8.411
46.8	11.50	140.4	7.945
50.4	11.71	144.0	7.447
54.0	11.89	147.6	6.910
57.6	12.03	151.2	6.334
61.2	12.13	154.8	5.715
64.8	12.21	158.4	5.053
68.4	12.25	162.0	4.344
72.0	12.26	165.6	3.584
75.6	12.25	169.2	2.774
79.2	12.21	172.8	1.908
82.8	12.15	176.4	0.984
86.4	12.06	180.0	0.000
90.0	11.97		

TABLE 1B - GEOMETRIC CHARACTERISTICS OF BARE HULL
EXPRESSED IN S. I. UNITS

Length, m	4.5720
Maximum diameter, m	0.6228
Wetted surface area, m^2	6.5545
Volume, m^3	0.8362
Longitudinal center of buoyancy, m	2.0373

Hull Offsets

X in metres	Y in metres	X in metres	Y in metres
0.0	0.0	2.3774	0.3002
0.0914	0.0889	2.4689	0.2962
0.1829	0.1264	2.5603	0.2918
0.2743	0.1551	2.6518	0.2868
0.3658	0.1790	2.7432	0.2812
0.4572	0.1994	2.8346	0.2751
0.5486	0.2171	2.9261	0.2682
0.6400	0.2327	3.0175	0.2608
0.7315	0.2463	3.1090	0.2528
0.8230	0.2583	3.2004	0.2442
0.9144	0.2687	3.2918	0.2348
1.0058	0.2776	3.3833	0.2246
1.0973	0.2855	3.4747	0.2136
1.1887	0.2921	3.5662	0.2018
1.2802	0.2974	3.6576	0.1892
1.3716	0.3020	3.7490	0.1755
1.4630	0.3056	3.8405	0.1609
1.5545	0.3081	3.9319	0.1452
1.6459	0.3101	4.0234	0.1283
1.7374	0.3112	4.1148	0.1103
1.8288	0.3114	4.2062	0.0910
1.9202	0.3112	4.2977	0.0704
2.0117	0.3101	4.3891	0.0485
2.1031	0.3086	4.4806	0.0250
2.1946	0.3063	4.5720	0.0
2.2860	0.3040		

slope of the hull at the mounting points. A sketch of the general planform and the dimensions common to all of the planes are presented in Figure 1.

When the planes were mounted on the tail cone of the model, the trailing edges were normal to the longitudinal axis of the body. The position of the trailing edges of the sternplanes was maintained at 7.9 inches (0.201 metres) forward of the AP. The rudders were 2.25 inches (0.057 metres) forward of the sternplanes. The spans and tip chords were varied in a systematic way so that the sternplanes had four different outreaches from the centerline of the model, and for each outreach there were five sets of planes with different tip chords. The outreaches of the sternplanes were 9, 12, 14.5, and 17.5 inches (0.228, 0.3048, 0.3683 and 0.4445 metres). The tip chords were 3, 5, 7, 9, and 11 inches (0.0762, 0.1270, 0.1778, 0.2286, and 0.2794 metres). Because of the longitudinal offset between the rudders and sternplanes, the outreach of the rudders was, in each case, 0.48 inches (1.22 centimetres) greater than their matching sternplanes.

The geometric characteristics of the sternplanes are given in Tables 2a and 2b. Figure 2 is a sketch of the model with control surfaces.

TEST APPARATUS AND PROCEDURE

The experimental work was conducted in the deep-water basin on Towing Carriage 2 using the DTNSRDC Planar-Motion-Mechanism System.[2]

The model was supported by two struts in tandem, 6 feet (1.829 metres) apart. The reference point was the center of buoyancy of the bare hull and was located midway between the gimbal-centers associated

[2] Gertler, Morton, "The DTMB Planar-Motion-Mechanism System," NSRDC Report 2523 (July 1967).

Sweep Angle of Quarter Chord = 15.25 degrees

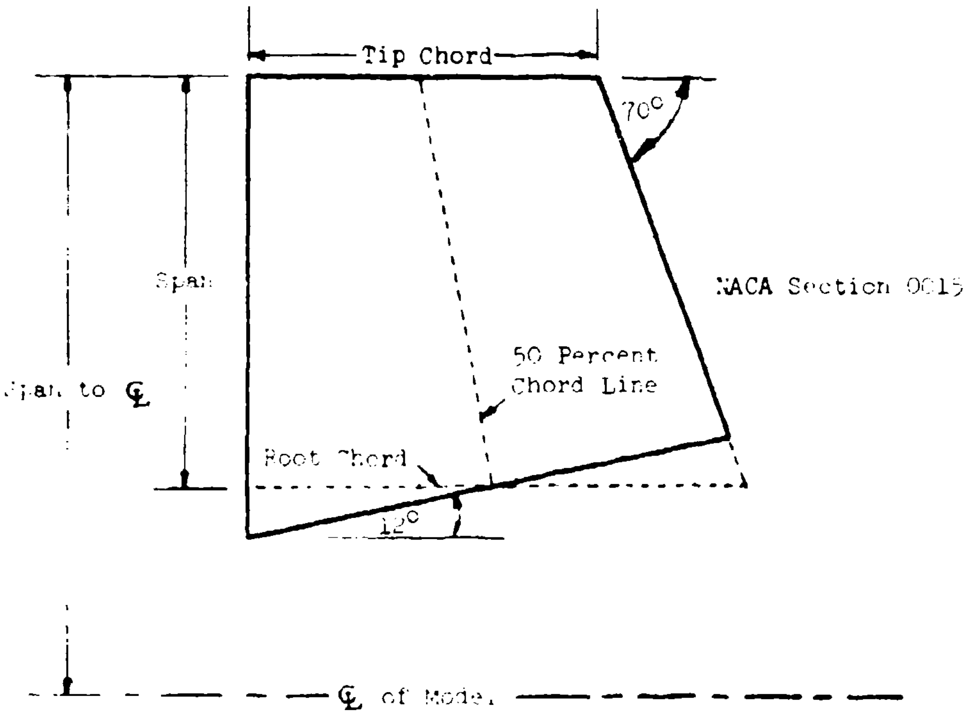


Figure 1 - Sketch of Representative Control Surface

All dimensions are in feet (metres)

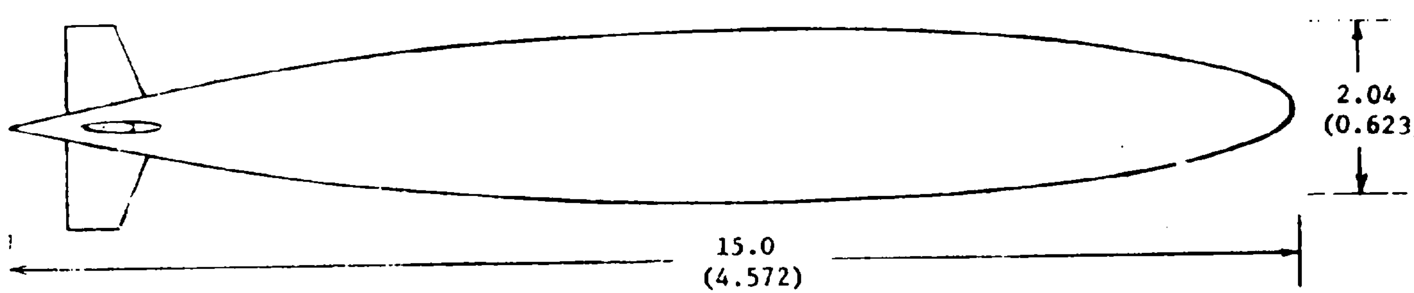


Figure 2 - Sketch of Model 4621 with Control Surfaces

TABLE 2A - GEOMETRIC CHARACTERISTICS OF STERNPLANES EXPRESSED IN U.S. CUSTOMARY UNITS

Span A

(Values are for 1 sternplane)

Sternplanes	3A	5A	7A	9A	11A
Span from ℄ of hull, in.	9.0	9.0	9.0	9.0	9.0
Tip chord, in.	3.0	5.0	7.0	9.0	11.0
Root chord, in.	5.24	7.17	9.10	11.03	12.96
Taper ratio	0.57	0.70	0.77	0.82	0.85
Span, distance from root chord to tip chord, in.	6.16	5.96	5.77	5.57	5.37
Projected area, sq. in.	25.4	36.2	46.3	55.6	64.0
Aspect ratio	1.50	0.98	0.72	0.56	0.45
Projected area of 1 plane extended to hull centerline, sq. in.	41.75	59.75	77.75	95.75	113.75
Aspect ratio of 1 plane extended to hull centerline	1.94	1.36	1.04	0.85	0.71

TABLE 2a (continued)

Span B

(Values are for 1 sternplane)

Sternplanes	3B	5B	7B	9B	11B
Span from ℄ of hull, in.	12.0	12.0	12.0	12.0	12.0
Tip chord, in.	3.0	5.0	7.0	9.0	11.0
Root chord, in.	6.30	8.22	10.14	12.08	14.01
Taper ratio	0.48	0.61	0.69	0.75	0.79
Span, distance from root chord to tip chord, in.	9.06	8.86	8.66	8.46	8.26
Projected area, sq. in.	42.0	58.4	74.1	88.9	103.0
Aspect ratio	1.95	1.34	1.01	0.81	0.66
Projected area of 1 plane extended to hull centerline, sq. in.	62.2	86.2	110.2	134.2	158.2
Aspect ratio of 1 plane extended to hull centerline	2.32	1.67	1.31	1.07	0.91

TABLE 2a (continued)

Span C

(Values are for 1 sternplane)

Sternplanes	3C	5C	7C	9C	11C
Span from ℄ of hull, in.	14.5	14.5	14.5	14.5	14.5
Tip chord, in.	3.0	5.0	7.0	9.0	11.0
Root chord, in.	7.18	9.11	11.04	12.97	14.88
Taper ratio	0.42	0.55	0.63	0.69	0.74
Span, distance from root chord to tip chord, in.	11.46	11.27	11.07	10.87	10.68
Projected area, sq. in.	58.2	79.3	99.6	119.1	137.8
Aspect ratio	2.26	1.60	1.23	0.99	0.83
Projected area of 1 plane extended to hull centerline, sq. in.	81.75	110.75	139.75	168.75	197.75
Aspect ratio of 1 plane extended to hull centerline	2.57	1.90	1.50	1.25	1.06

TABLE 2a (continued)

Span D

(Values are for 1 sternplane)

Sternplanes	3D	5D	7D	9D	11D
Span from ℄ of hull, in.	17.5	17.5	17.5	17.5	17.5
Tip chord, in.	3.0	5.0	7.0	9.0	11.0
Root chord, in.	8.22	10.16	12.09	14.02	15.94
Taper ratio	0.37	0.49	0.58	0.64	0.69
Span, distance from root chord to tip chord, in.	14.36	14.16	13.96	13.76	13.57
Projected area, sq. in.	80.5	107.1	132.9	158.0	182.3
Aspect ratio	2.56	1.87	1.47	1.20	1.01
Projected area of 1 plane extended to hull centerline, sq. in.	108.2	143.2	178.2	213.2	248.2
Aspect ratio of 1 plane extended to hull centerline	2.83	2.14	1.72	1.44	1.23

TABLE 2B - GEOMETRIC CHARACTERISTICS OF STERNPLANES
EXPRESSED IN S. I. UNITS

Span A

(Values for one sternplane)

Sternplanes	3A	5A	6A	9A	11A
Span from ℄ of hull, cm	22.86	22.86	22.86	22.86	22.86
Tip chord, cm	7.62	12.70	17.78	22.86	27.94
Root chord, cm	13.31	18.21	23.11	28.02	32.92
Taper ratio	0.57	0.70	0.77	0.82	0 85
Span, distance from root chord to tip chord, cm	15.65	15.14	14.66	14.15	13.64
Projected area, cm^2	163.87	233.55	298.71	358.71	412.90
Aspect ratio	1.50	0.98	0.72	0.56	0.45
Projected area of 1 plane extended to hull centerline, cm^2	269.35	385.48	501.61	617.74	733.87
Aspect ratio of 1 plane extended to hull centerline	1.94	1.36	1.04	0.85	0.71

TABLE 2b (continued)

Span B

(Values for one sternplane)

Sternplanes	3B	5B	7B	9B	11B
Span from C_L of hull, cm	30.48	30.48	30.48	30.48	30.48
Tip chord, cm	7.62	12.70	17.78	22.86	27.94
Root chord, cm	16.00	20.88	25.76	30.68	35.58
Taper ratio	0.48	0.61	0.69	0.75	0.79
Span, distance from root chord to tip chord, cm	23.01	22.50	22.00	21.49	20.98
Projected area, cm^2	270.97	376.77	478.06	573.55	664.51
Aspect ratio	1.95	1.34	1.01	0.81	0.66
Projected area of 1 plane extended to hull centerline, cm^2	401.29	556.13	710.97	865.80	1020.60
Aspect ratio of 1 plane extended to hull centerline	2.32	1.67	1.31	1.07	0.91

TABLE 2b (continued)

Span C

(Values for one sternplane)

Sternplanes	3C	5C	7C	9C	11C
Span from $\mathcal{C}_L$ of hull, cm	36.83	36.83	36.83	36.83	36.83
Tip chord, cm	7.62	12.70	17.78	22.86	27.94
Root chord, cm	18.24	23.14	28.04	32.94	37.79
Taper ratio	0.42	0.55	0.63	0.69	0.74
Span, distance from root chord to tip chord, cm	29.11	28.62	28.12	27.61	27.13
Projected area, cm^2	375.48	511.61	642.58	768.38	889.03
Aspect ratio	2.26	1.60	1.23	0.99	0.83
Projected area of 1 plane extended to hull center-line, cm^2	527.42	714.51	901.61	1088.71	1275.80
Aspect ratio of 1 plane extended to hull centerline	2.57	1.90	1.50	1.25	1.06

TABLE 2b (continued)

Span D

(Values for one sternplane)

Sternplanes	3D	5D	7D	9D	11D
Span from C_L of hull, cm	44.45	44.45	44.45	44.45	44.45
Tip chord, cm	7.62	12.70	17.78	22.86	27.94
Root chord, cm	20.88	25.81	30.71	35.61	40.49
Taper ratio	0.37	0.49	0.58	0.64	0.69
Span, distance from root chord to tip chord, cm	36.47	35.97	35.46	34.95	34.47
Projected area, cm^2	519.35	690.97	857.42	1019.35	1176.13
Aspect ratio	2.56	1.87	1.47	1.20	1.01
Projected area of 1 plane extended to hull centerline, cm^2	698.06	923.87	1149.68	1375.48	1601.29
Aspect ratio of 1 plane extended to hull centerline	2.83	2.14	1.72	1.44	1.23

with the two struts. The longitudinal and normal force components with respect to the body axes were measured by means of internal force balances located at each strut. All of the tests were run at a depth of 10 feet (3.048 metres) to the centerline and at a speed of 6 knots which corresponds to a Reynolds number of 1.4×10^7 based on model length.

The experimental program consisted of static stability tests on the bare hull and on the hull appended with each of the 20 sets of control surfaces. The forces and moments were measured over a range of angles of attack from -6 to 18 degrees. The control surface angle settings were zero at all times. To stimulate turbulence a sandstrip was installed on the hull 9 inches (0.229 metres) aft of the nose.

REDUCTION AND PRESENTATION OF DATA

The data obtained from the captive-model experiments are presented in nondimensional form in the appendixes. The organization of the appendixes is as follows:

Appendix A contains a derivation of an equation for representing the ratio $C_{Z\alpha}/C_{L\alpha}$ as a function of the parameter 2b/d. Appendix B contains plots of the nondimensional hydrodynamic coefficients X', Z', and M' as functions of angle of attack. Data for the bare body as well as for the body appended with each of the twenty sternplane configurations are presented. Appendix C presents tabulations of data shown in the plots in Appendix B. Appendix D contains tabulations of the derivatives Z_w', M_w', $\Delta Z_w'$, $\Delta M_w'$, $C_{Z\alpha}$, $C_{L\alpha}$ which apply to each configuration.

Summary figures based on the data obtained from the experiments are given in the body of the report.

DISCUSSION OF RESULTS

As mentioned in an earlier section, the major objective of this investigation was to determine the contributions of control surfaces to the forces and moments on the total fin-body combinations in order to obtain information that would be useful in the preliminary design of submarines from a stability point of view.

In accordance with this objective, the stability derivatives Z_w' and M_w' were determined for all configurations by taking the slopes, at the origin, of the curves shown in Appendix B of Z' and M' versus angle of attack and converting them to "per radian" measure. The values of Z_w' and M_w' for the bare hull were then subtracted from the corresponding derivatives for the body with control surfaces to obtain the incremental effects which are referred to in this report as $\Delta Z_w'$ and $\Delta M_w'$.

In order to divorce the incremental effects of the control surfaces from the length of the particular body on which they were tested, the values of $(-\Delta Z_w')$ were re-nondimensionalized using the projected area, $2A$, of the two sternplanes extended through the body. Since for small angles $L \approx -Z$ and $\alpha \approx w'$, this procedure in effect converted the increments into lift-curve slopes, $C_{Z\alpha}$, which could be compared with free-stream results.

The work done by Whicker and Fehlner (Reference 1) has shown that good correlation exists between experimentally-obtained lift-curve

slopes for low-aspect-ratio control surfaces in the free stream and the following semi-empirical expression for lift-curve slope

$$C_{L\alpha} = \frac{1.8\pi a}{1.8 + \cos\Lambda\left(\frac{a^2}{\cos^4\Lambda} + 4\right)^{\frac{1}{2}}} \tag{1}$$

where

$C_{L\alpha}$ = slope of lift coefficient with respect to angle of attack α in radians at $\alpha = 0$

a = effective aspect ratio

Λ = sweep angle of quarter chord line

Values of $C_{L\alpha}$ for various effective aspect ratios and a sweep angle of 15.25 degrees were computed from this equation and were plotted as a function of effective aspect ratio in Figure 3. The derivatives $C_{Z\alpha}$ from the sternplane series were also plotted in Figure 3 as functions of their respective effective aspect ratios (aspect ratios of the sternplanes through the body). It can be seen from the figure that the experimental values of $C_{Z\alpha}$ (indicated by the symbols) are functions of outreach as well as of aspect ratio.

The solid lines drawn through the data points were determined in the following manner: For each span parameter, $\frac{2b}{d}$, the ratios of the experimental values of $C_{Z\alpha}$ to the corresponding values of $C_{L\alpha}$ from Equation (1) were computed. Then the average of these ratios was computed and a curve was constructed by multiplying the values of $C_{L\alpha}$ by this average ratio.

Figure 4 is a plot of the average ratios, $\frac{C_{Z\alpha}}{C_{L\alpha}}$, as a function of the span parameter, $\frac{2b}{d}$. The curve joining the symbols is the following

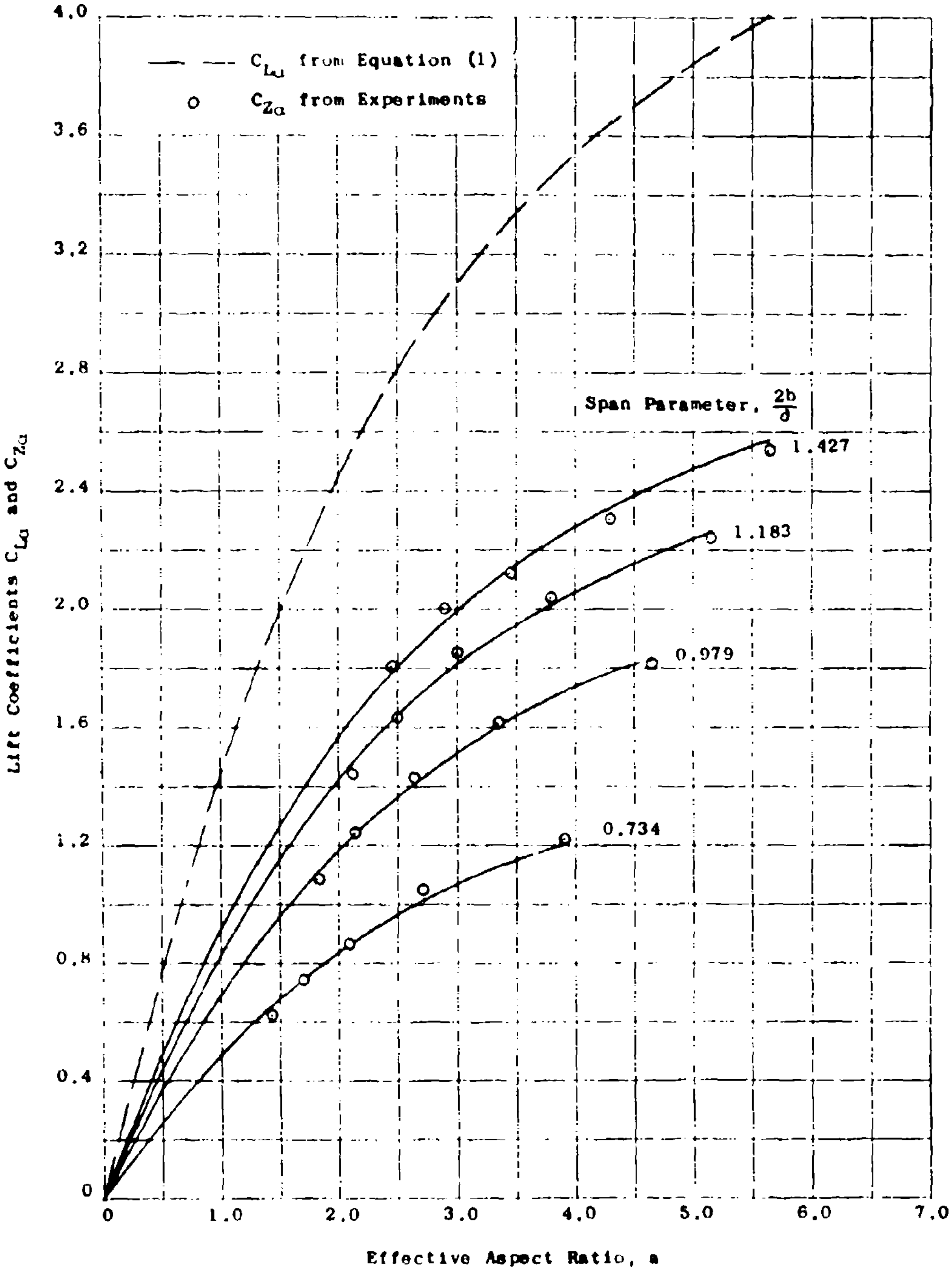


Figure 3 - Variation of $C_{Z\alpha}$ and $C_{L\alpha}$ with Effective Aspect Ratio for Various Span Parameters

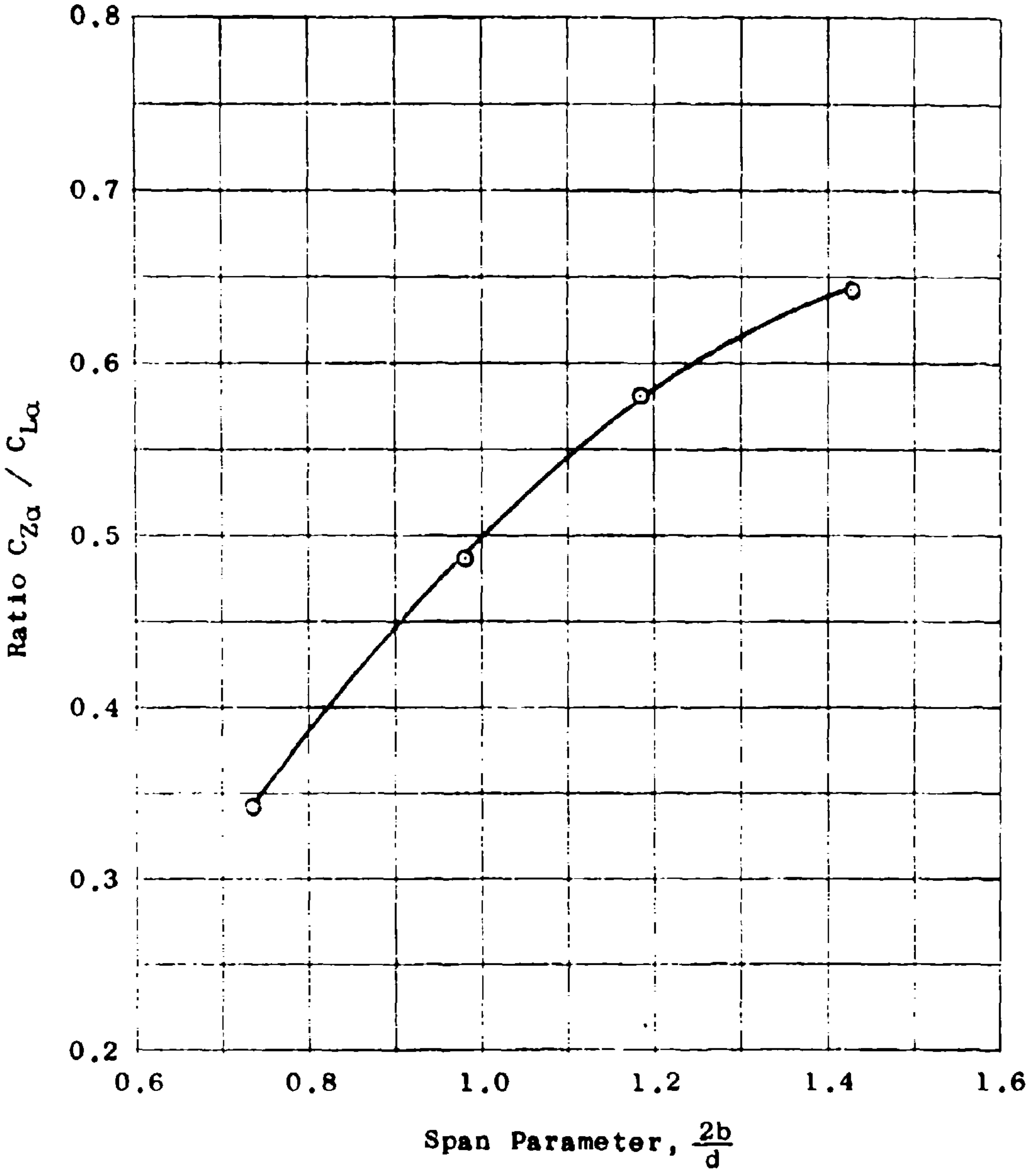


Figure 4 - Variation of the Ratio $C_{Z\alpha}/C_{L\alpha}$ with Span Parameter

least-squares fit of the points:

$$\frac{C_{Z\alpha}}{C_{L\alpha}} = -0.3644 + 1.2380 \left(\frac{2b}{d}\right) -0.3728 \left(\frac{2b}{d}\right)^2 \tag{2}$$

for the range $0.734 \leq 2b/d \leq 1.426$.

Combining Equations (1) and (2),

$$C_{Z\alpha} = -\frac{1.8\pi a}{1.8 + \cos\Lambda\left(\frac{a^2}{\cos^4\Lambda} + 4\right)^{\frac{1}{2}}} \left[0.3644 - 1.2380 \left(\frac{2b}{d}\right) + 0.3728 \left(\frac{2b}{d}\right)^2\right] \tag{3}$$

Equation (3) may be used to compute the contribution to $Z_w{}'$ of a given set of sternplanes on a given streamline body as follows:

since

$$C_{Z\alpha} = -\Delta Z_w{}' \frac{\ell^2}{2A}$$

and the effective aspect ratio of the sternplanes extended through the body is

$$a = \frac{2b^2}{A}$$

then

$$\Delta Z_w{}' = \frac{1.8\pi}{1.8 + \cos\Lambda\left(\frac{a^2}{\cos^4\Lambda} + 4\right)^{\frac{1}{2}}} \left(\frac{2b}{\ell}\right)^2 \left[0.3644 - 1.2380 \left(\frac{2b}{d}\right) + 0.3728 \left(\frac{2b}{d}\right)^2\right] \tag{4}$$

for the range $0.734 \leq 2b/d \leq 1.426$.

While Equation (2) gives a very good representation of the ratio $\frac{C_{Z\alpha}}{C_{L\alpha}}$ for values of $\frac{2b}{d}$ in the range between 0.734 and 1.426, extrapolations

beyond this range cannot be relied upon. As the span of the sternplanes approaches infinity the ratio $\frac{C_{Z\alpha}}{C_{L\alpha}}$ should approach unity. Equation (2) does not satisfy this condition since it reaches a maximum value of 0.663 at $\frac{2b}{d} = 1.6604$ and becomes zero at $\frac{2b}{d} = 2.994$.

An alternate equation for representing the ratio $\frac{C_{Z\alpha}}{C_{L\alpha}}$ is derived in Appendix A. This equation fits the experimental data slightly less well than Equation (2) but has the advantage of becoming unity at $\frac{2b}{d} = \infty$. For this reason it is recommended that this alternate equation which is

$$\frac{C_{Z\alpha}}{C_{L\alpha}} = 1 - \frac{0.2556}{(\frac{2b}{d})^2} [(\frac{2b}{d})^2 - 0.1612]^{\frac{1}{2}} - 0.6366 \sin^{-1}(\frac{0.4015}{2b/d}) \qquad (5)$$

be used for $0.4015 < \frac{2b}{d} < 0.734$ and $1.426 < \frac{2b}{d} < \infty$

The use of Equation (5) then gives the following equation for $\Delta Z_w'$:

$$\Delta Z_w' = - \frac{1.8\pi}{1.8 + \cos\Lambda(\frac{a^2}{\cos^4\Lambda} + 4)^{\frac{1}{2}}} (\frac{2b}{\ell})^2 \Bigg\{ 1 - \frac{0.2556}{(\frac{2b}{d})^2} \qquad (6)$$

$$\bullet [(\frac{2b}{d})^2 - 0.1612]^{\frac{1}{2}} - 0.6366 \sin^{-1}(\frac{0.4015}{2b/d}) \Bigg\}$$

for $0.4015 < \frac{2b}{d} < 0.734$ and $1.426 < \frac{2b}{d} < \infty$

The longitudinal positions of the center of pressure of the forces due to the sternplanes with respect to the hull LCB were determined by the ratios $\frac{\Delta M_w'}{\Delta Z_w'}$. These center-of-pressure locations were then referred to the trailing edge of the sternplanes and the resulting distances were nondimensionalized by the mean chords $\bar{c}$.

Figure 5 shows a plot of the center of pressure locations as functions of effective aspect ratio. Although there is considerable scatter in the data, particularly for the A sternplane series, it can be seen that for a given aspect ratio the center of pressure in general moves forward as the span parameter $\frac{2b}{d}$ increases and, in some cases, is actually forward of the planes.

CONCLUSIONS

From the experimental results of this investigation empirical mathematical expressions have been developed to predict the contribution of sternplanes to the static stability derivative Z_w' when the sternplanes are appended to a submarine design whose basic hull is a streamlined body of revolution. A graphical method is provided to estimate the location of the center of pressure with respect to the trailing edge of the sternplanes.

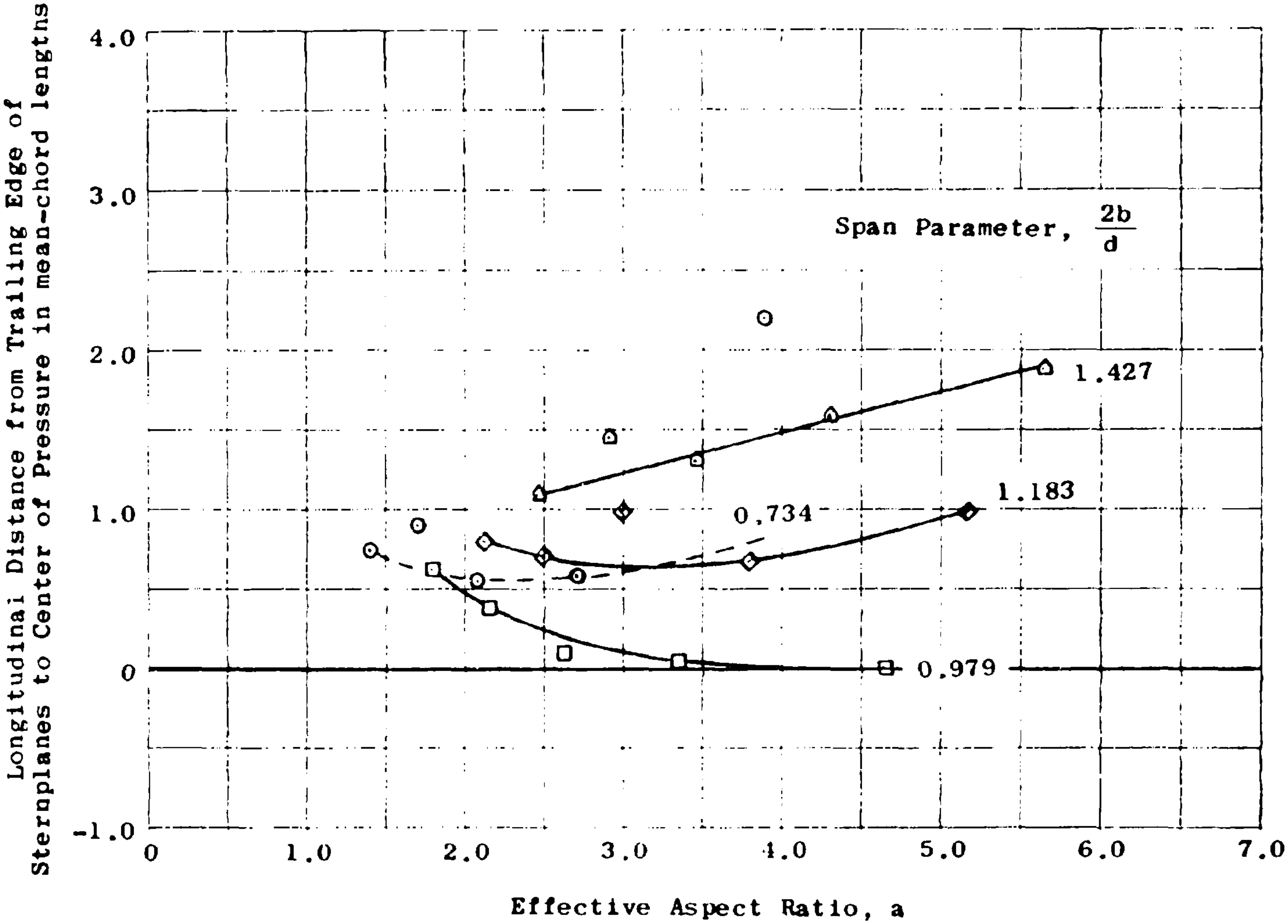


Figure 5 - Variation of Center-of-Pressure Location with Effective Aspect Ratio for Various Span Parameters

ACKNOWLEDGMENTS

The author wishes to express her appreciation to Messrs. A. Goodman and M. Gertler formerly of DTNSRDC who initiated this experimental program; to B. Carson, R. S. Dart, E. H. Dittrich, Dr. E. C. James, N. King, and T. Mahoney who participated in the experimental work; and to Dr. J. P. Feldman for his contributions and guidance.

APPENDIX A

DERIVATION OF AN EQUATION FOR REPRESENTING THE RATIO $\frac{C_{Z\alpha}}{C_{L\alpha}}$ AS A FUNCTION OF THE SPAN PARAMETER $\frac{2b}{d}$

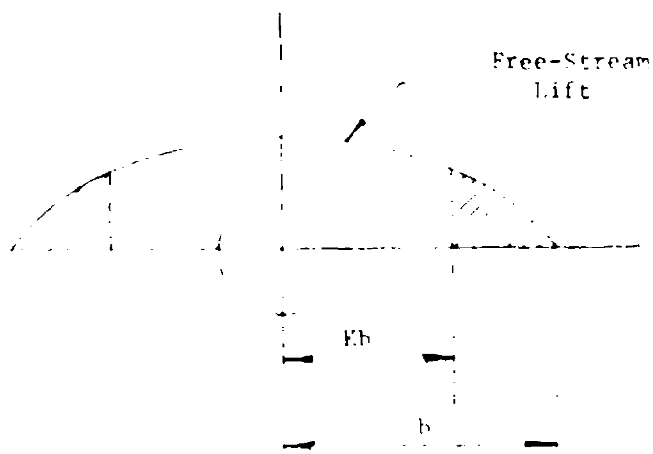
APPENDIX A

Derivation of an Equation for Representing the Ratio $\frac{C_{Z\alpha}}{C_{L\alpha}}$ as a Function of the Span Parameter $\frac{2b}{d}$

If the lift distribution on a control surface in the freestream is assumed to be elliptical, the lift, $C_{L\alpha}\alpha$, is proportional to

$$2\int_o^b \frac{\Gamma}{b}\left(b^2 - x^2\right)^{1/2} dx = \frac{\Gamma b\pi}{2}$$

If the lift due to sternplanes on a streamlined body of revolution is assumed to be proportional to the shaded area in the sketch



$C_{Z\alpha}\alpha$ is proportional to

$$2\int_{Kb}^b \frac{\Gamma}{b}\left(b^2 - x^2\right)^{1/2} dx = \Gamma b\left[\frac{\pi}{2} - K\left(1 - K^2\right)^{1/2} - \sin^{-1}K\right]$$

The ratio $\frac{C_{Z\alpha}}{C_{L\alpha}}$ is then

$$\frac{C_{Z\alpha}}{C_{L\alpha}} = 1 - \frac{2K}{\pi}(1 - K^2)^{\frac{1}{2}} - \frac{2}{\pi}\sin^{-1}K \tag{7}$$

A value of K for the average experimental value of $\frac{C_{Z\alpha}}{C_{L\alpha}}$ for each span was determined from Equation (7) and listed in Tabulation 1 together with $\frac{2b}{d}$, $\frac{C_{Z\alpha}}{C_{L\alpha}}$ and the product $K(\frac{2b}{d})$.

TABULATION 1

$\frac{2b}{d}$	$\frac{C_{Z\alpha}}{C_{L\alpha}}$	K	$K(\frac{2b}{d})$
0.734	0.3436	0.542	0.3978
0.978	0.4868	0.415	0.4059
1.182	0.5810	0.335	0.3960
1.426	0.6420	0.285	0.4064

It can be seen from Tabulation 1 that the values of $K(\frac{2b}{d})$ are essentially constant, giving an average value such that $K(\frac{2b}{d}) = 0.4015$ or $K = \frac{0.4015}{(\frac{2b}{b})}$.

This indicates that the "defect" in the effective span of the wing through the body is $2 \times Kb = 0.4015d$.

Substituting $\frac{0.4015}{(\frac{2b}{b})}$ for K in Equation (7) gives

$$\frac{C_{Z\alpha}}{C_{L\alpha}} = 1 - \frac{0.2556}{(\frac{2b}{d})^2} [(\frac{2b}{d})^2 - 0.1612]^{\frac{1}{2}} - 0.6366 \sin^{-1} (\frac{0.4015}{2b/d}) \qquad (8)$$

Tabulation 2 compares the values of $\frac{C_{Z\alpha}}{C_{L\alpha}}$ from the experiments with those computed from Equations (2) and (8).

TABULATION 2

$\frac{2b}{d}$	$\frac{C_{Z\alpha}}{C_{L\alpha}}$ Experimental	$\frac{C_{Z\alpha}}{C_{L\alpha}}$ Equation (2)	$\frac{C_{Z\alpha}}{C_{L\alpha}}$ Equation (8)
0.734	0.3436	0.3434	0.3400
0.978	0.4868	0.4898	0.4924
1.182	0.5810	0.5781	0.5760
1.426	0.6420	0.6420	0.6463

It can be seen that Equation (2) gives slightly better agreement with the experimental values of $\frac{C_{Z\alpha}}{C_{L\alpha}}$ than does Equation (8).

APPENDIX B

GRAPHICAL PRESENTATION OF LONGITUDINAL AND NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS AS FUNCTIONS OF ANGLE OF ATTACK

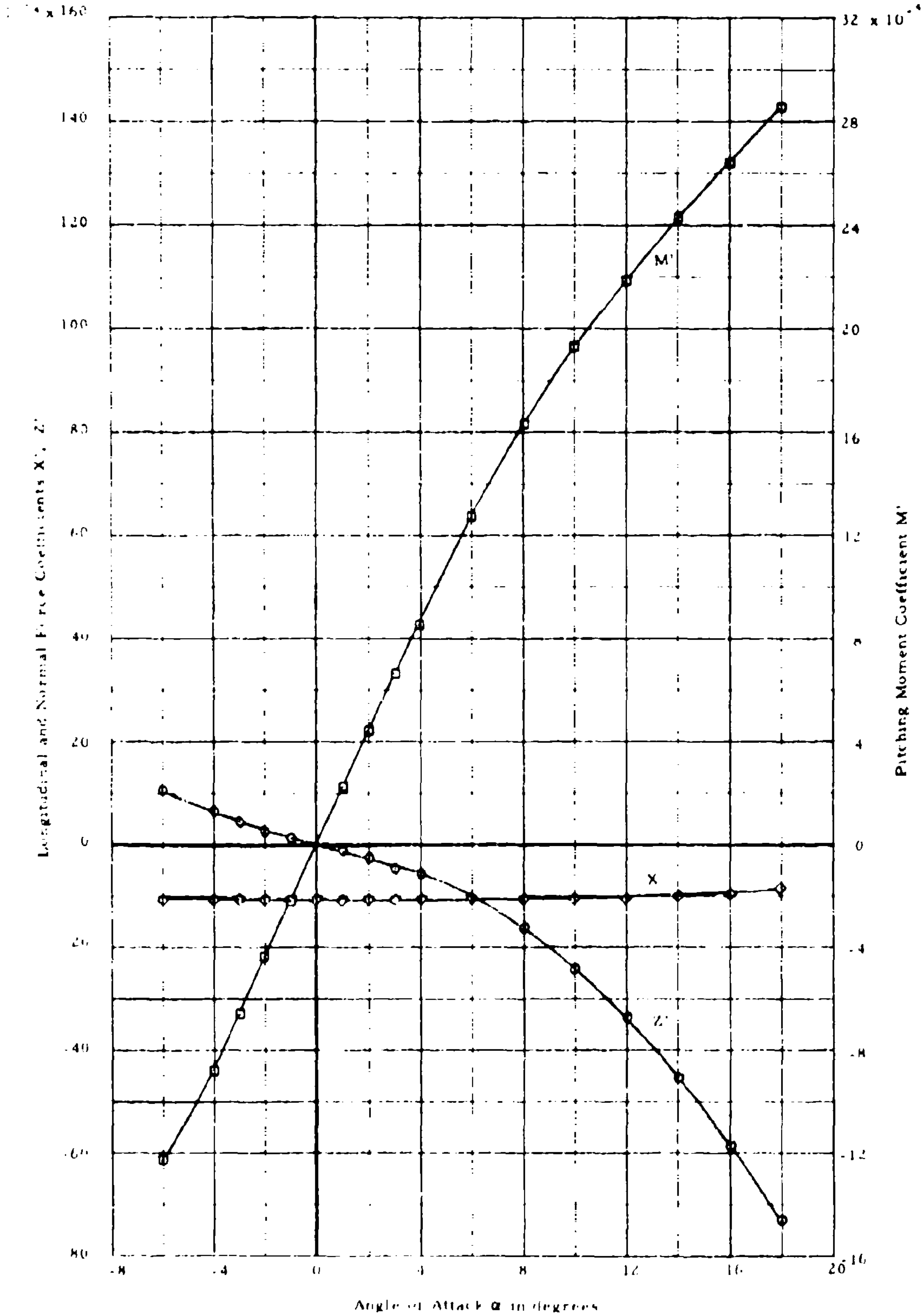


Figure 6 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Bare Body

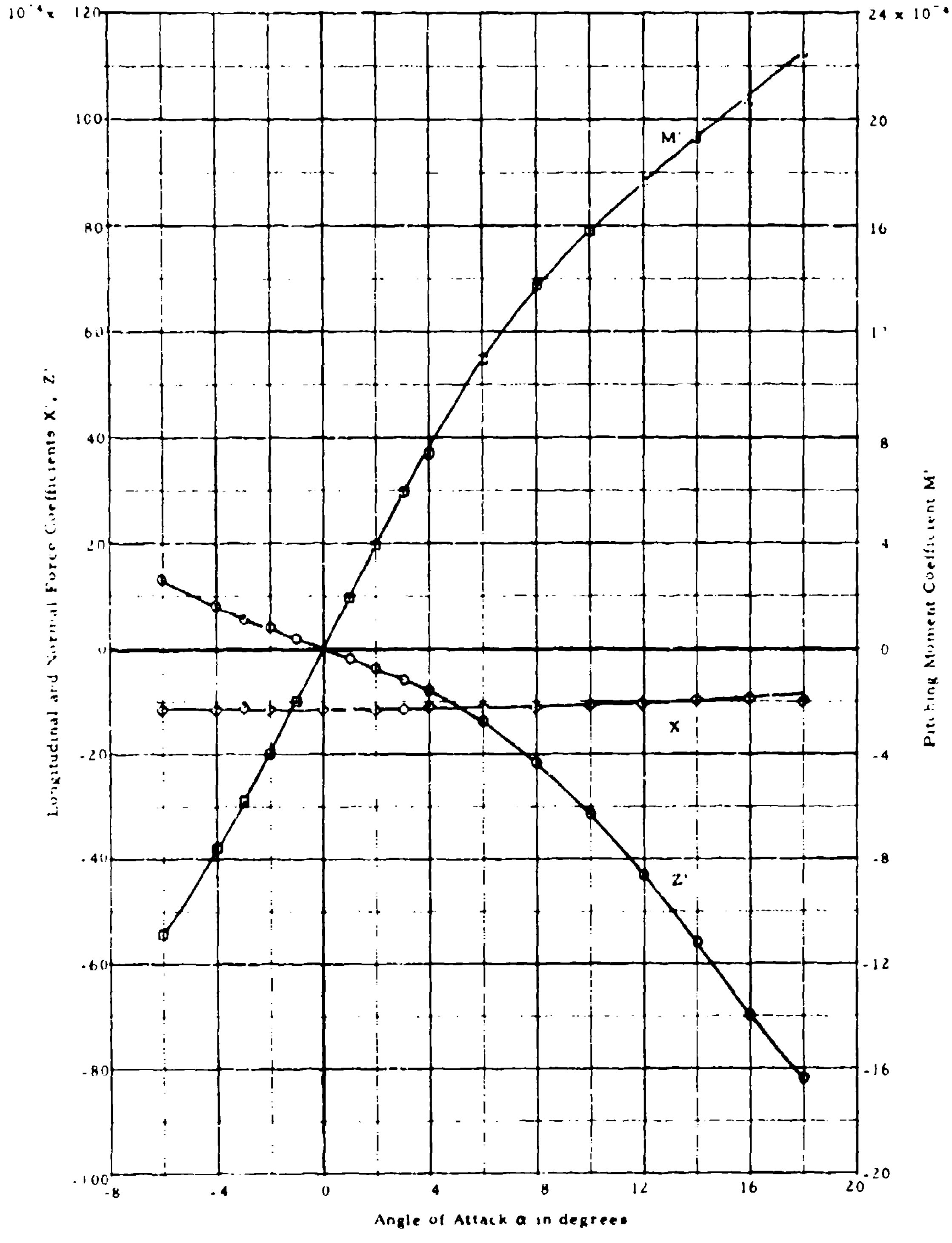


Figure 7 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 3A Sternplanes

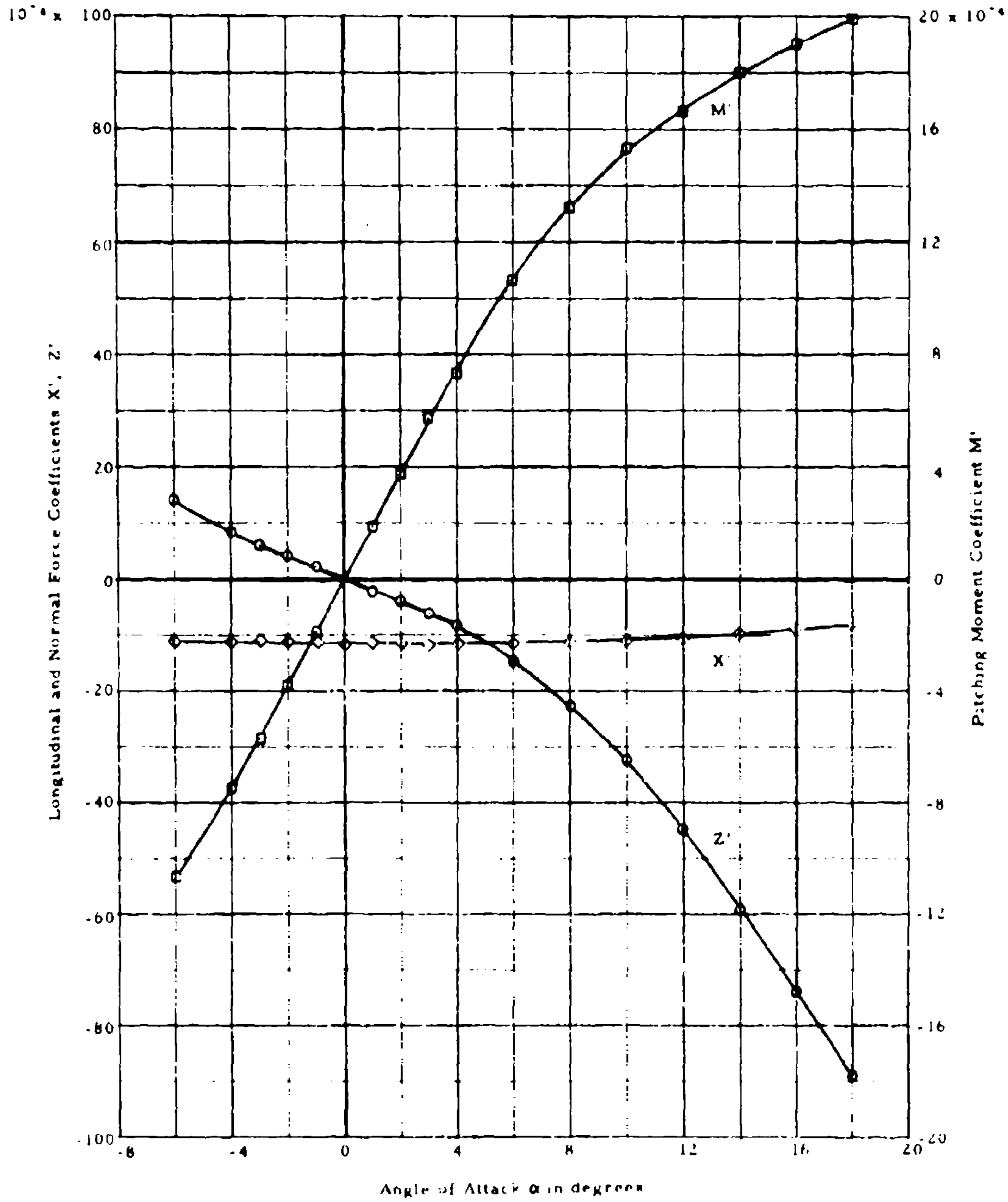


Figure 8 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 5A Sternplanes

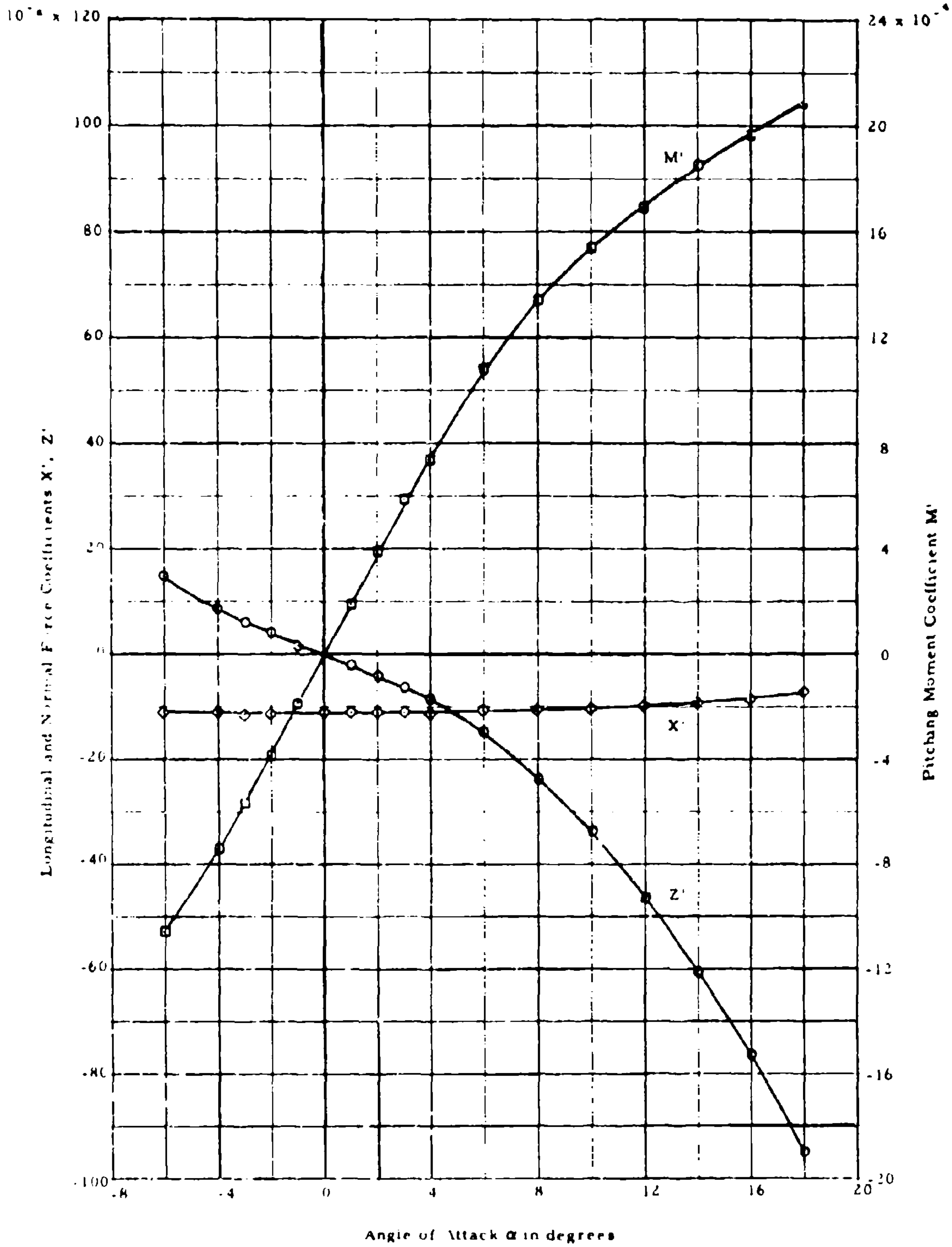


Figure 9 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 7A sternplanes

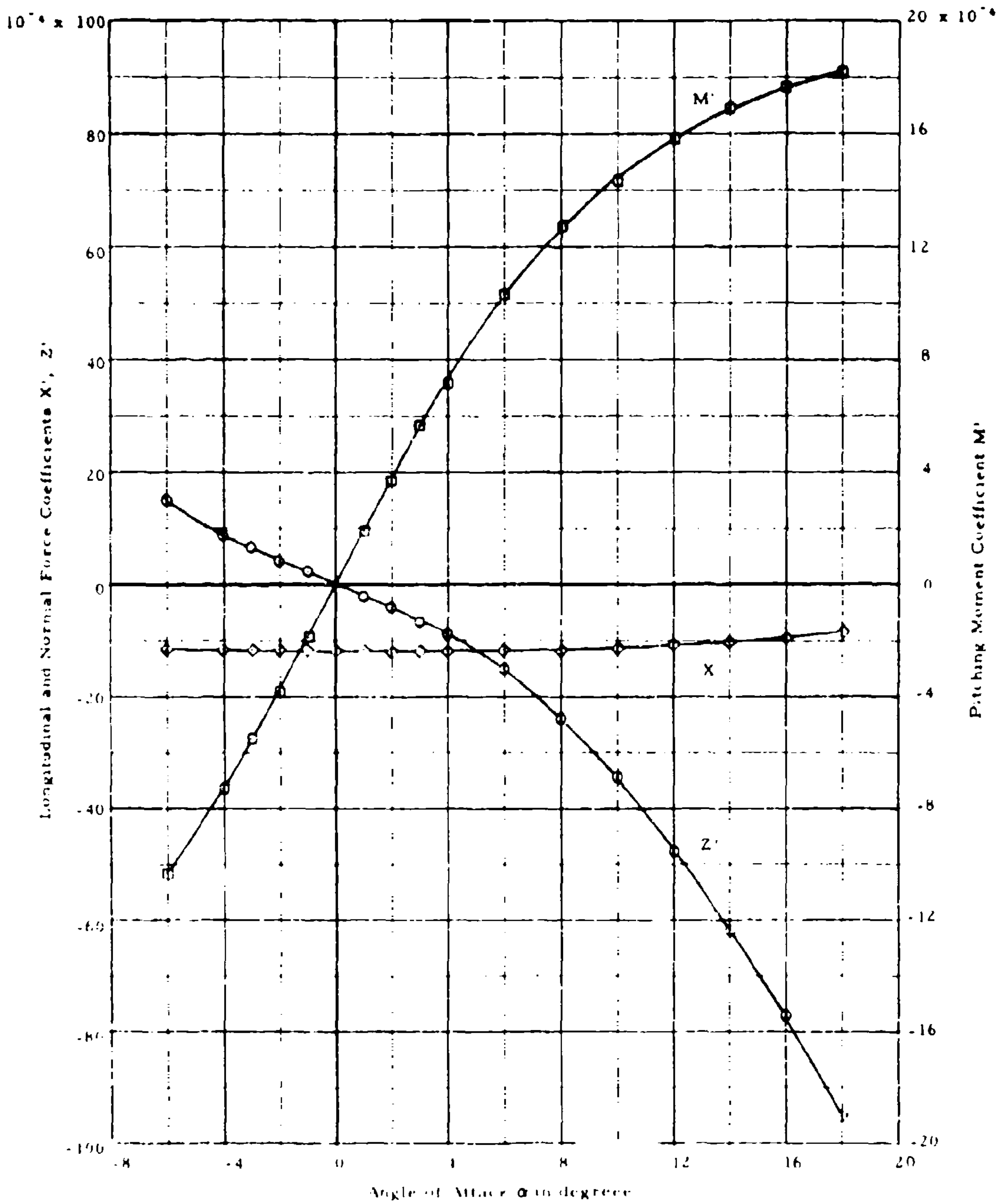


Figure 10 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 9A Sternplanes

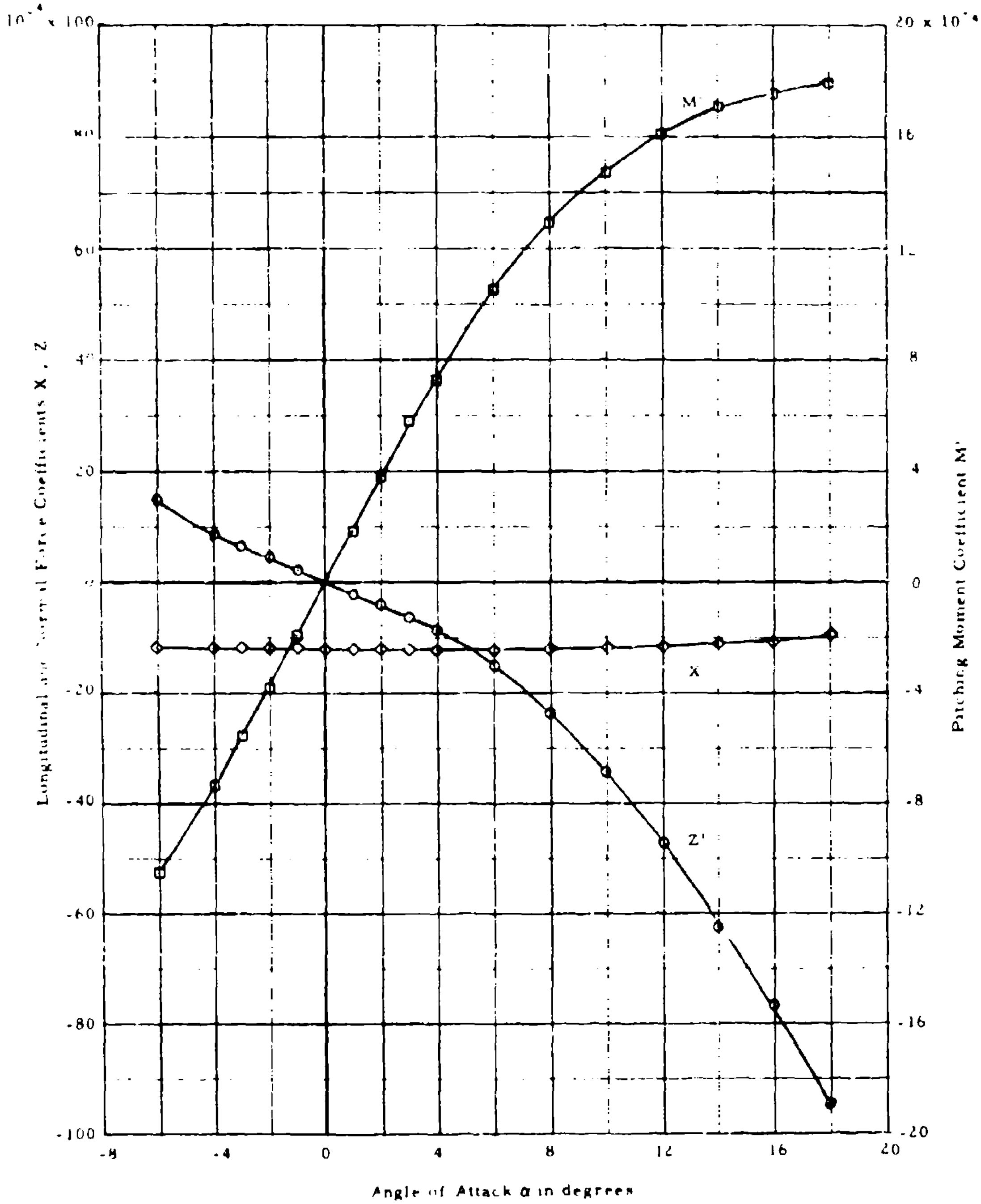


Figure 11 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 11A Sternplanes

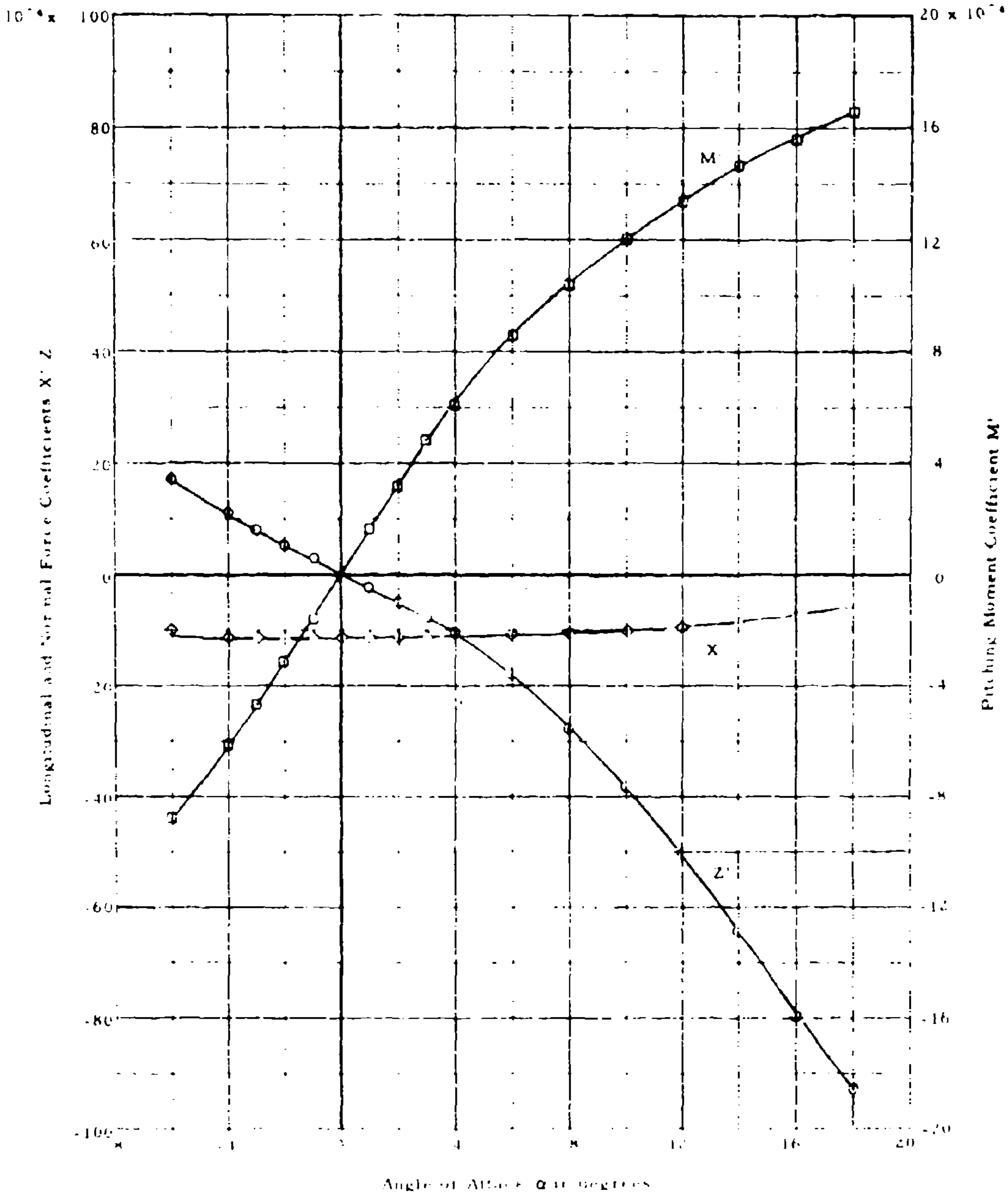


Figure 12 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 3B Sternplanes

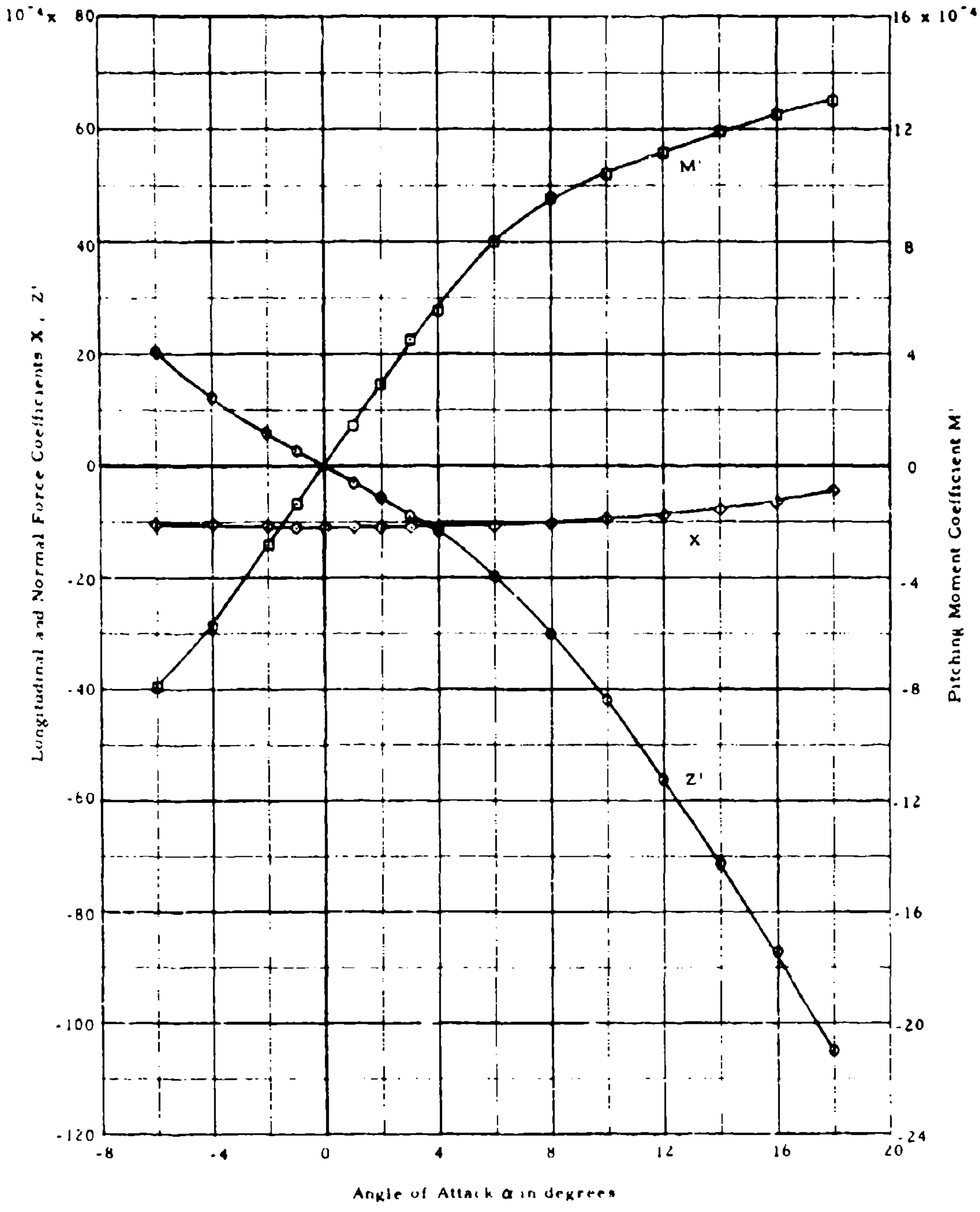


Figure 13 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 5B Sternplanes

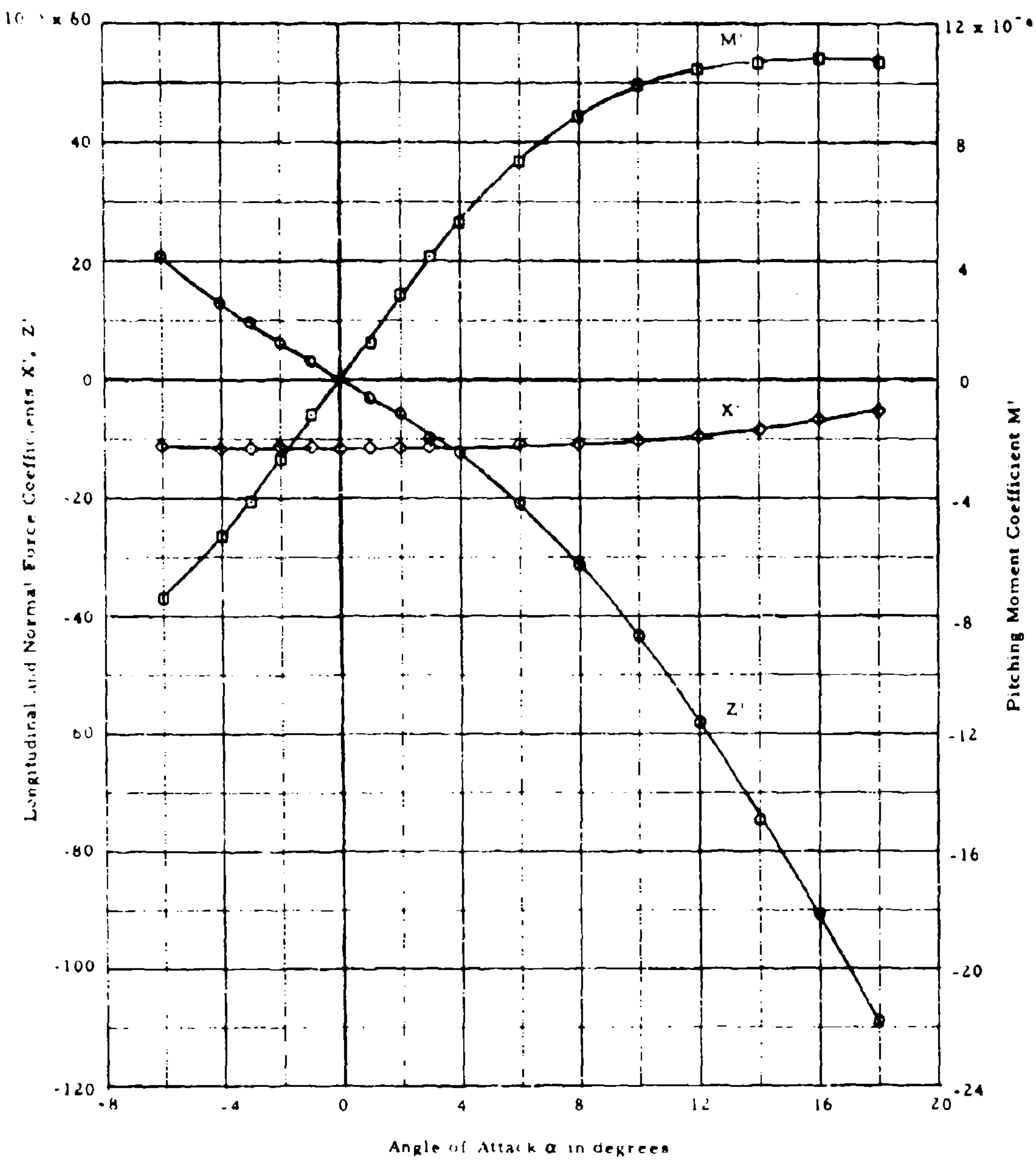


Figure 14 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 7B Sternplanes

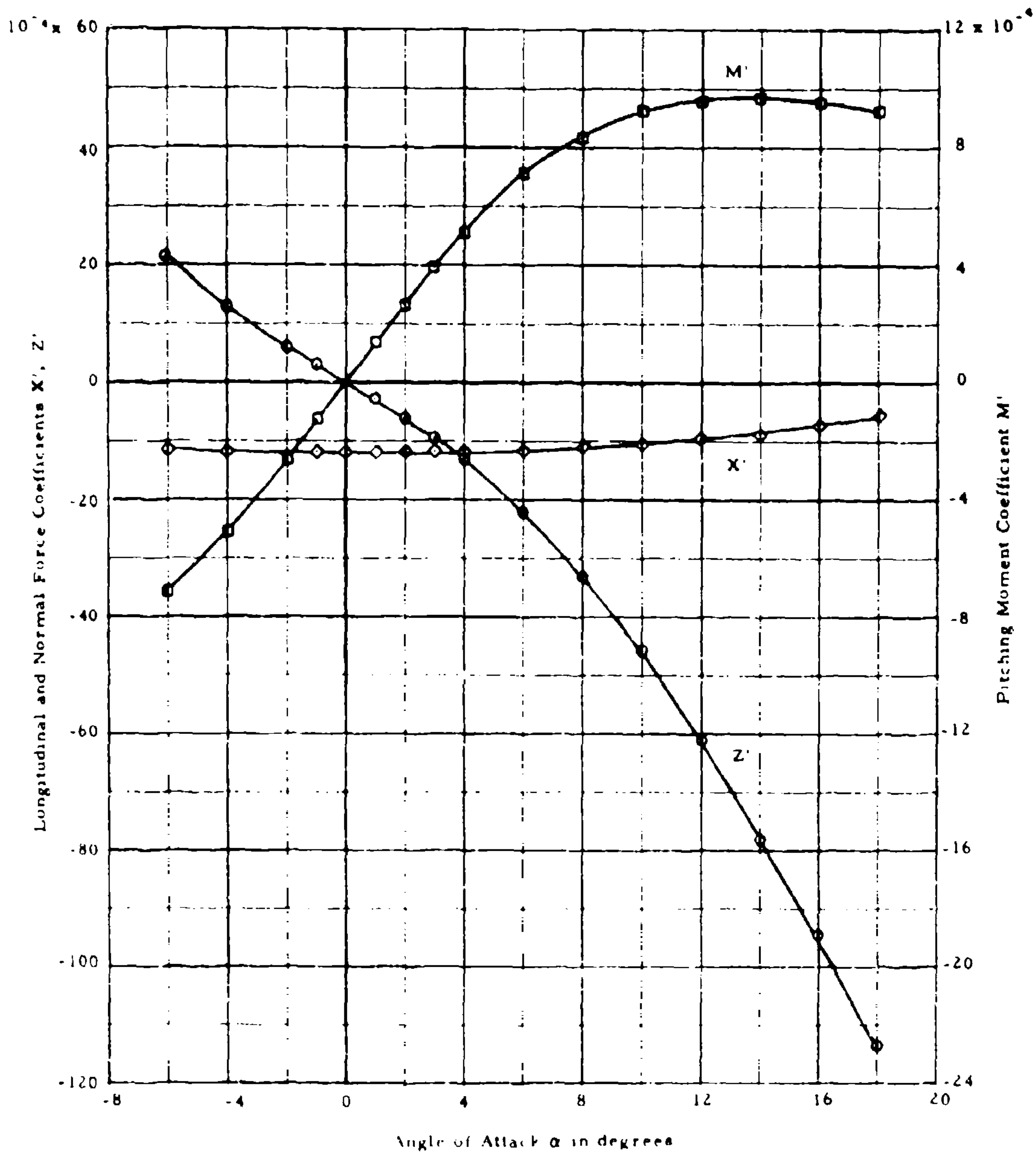


Figure 15 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 9B Sternplanes

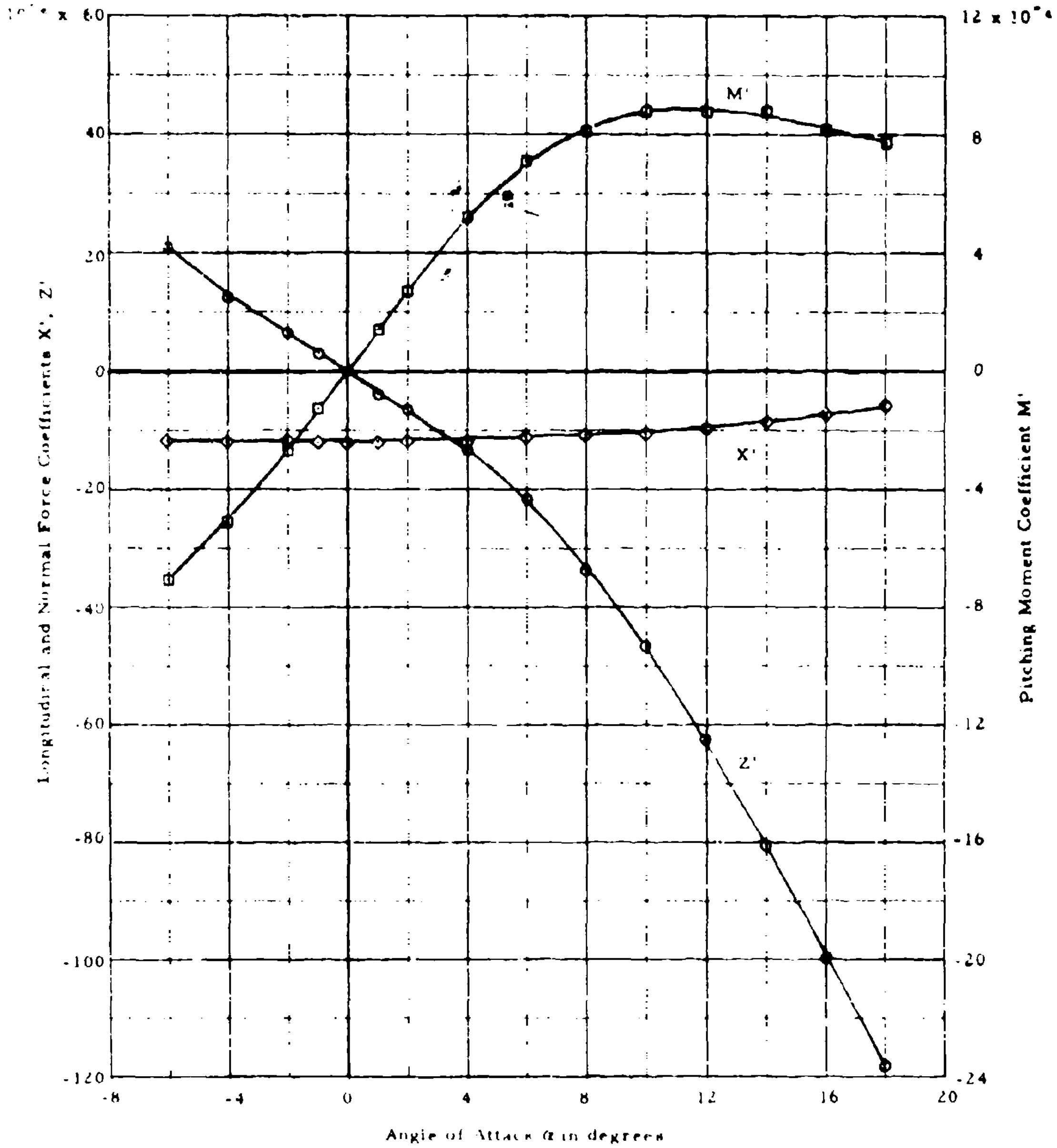


Figure 16 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 11B Sternplanes

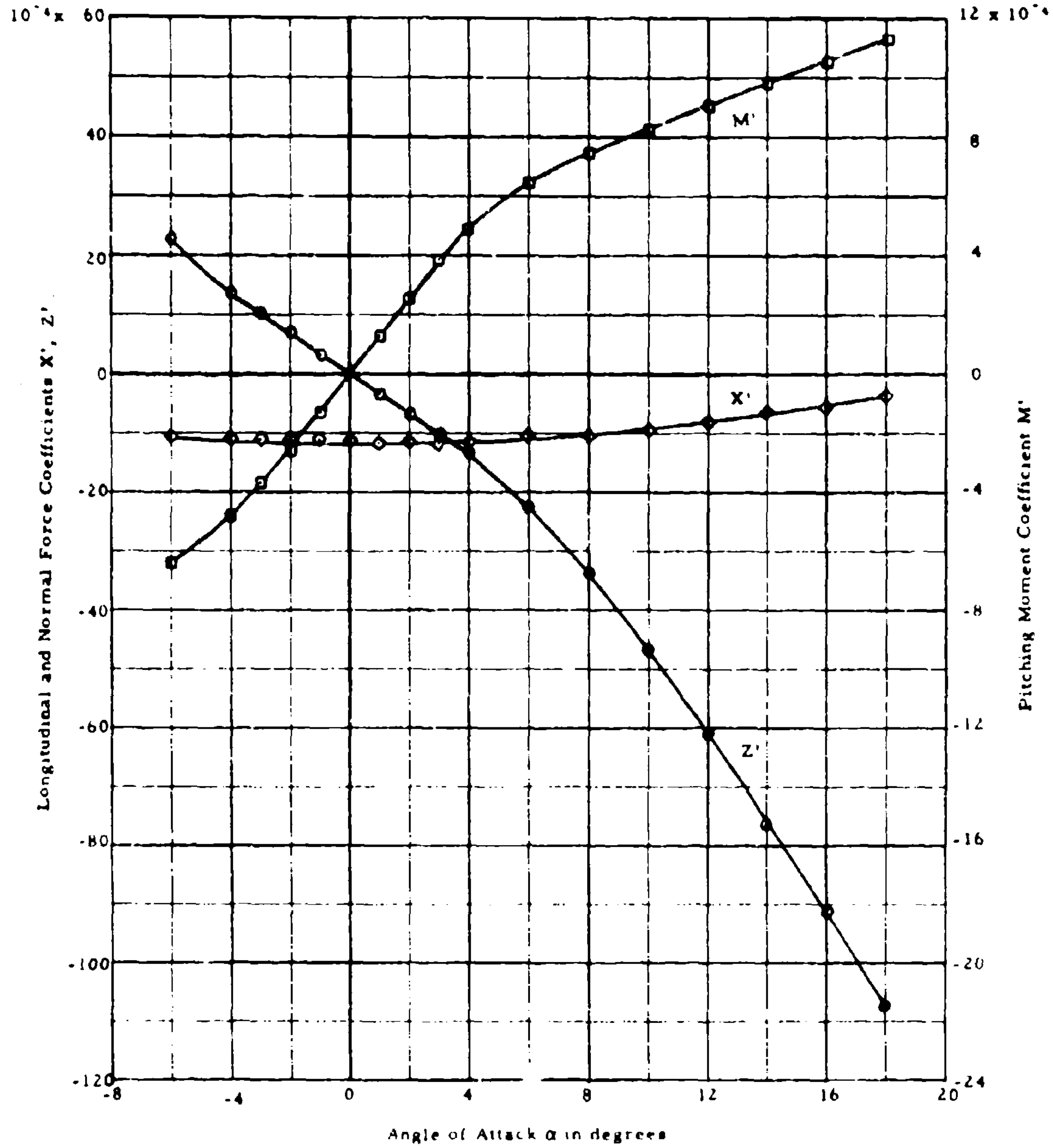


Figure 17 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 3C Sternplanes

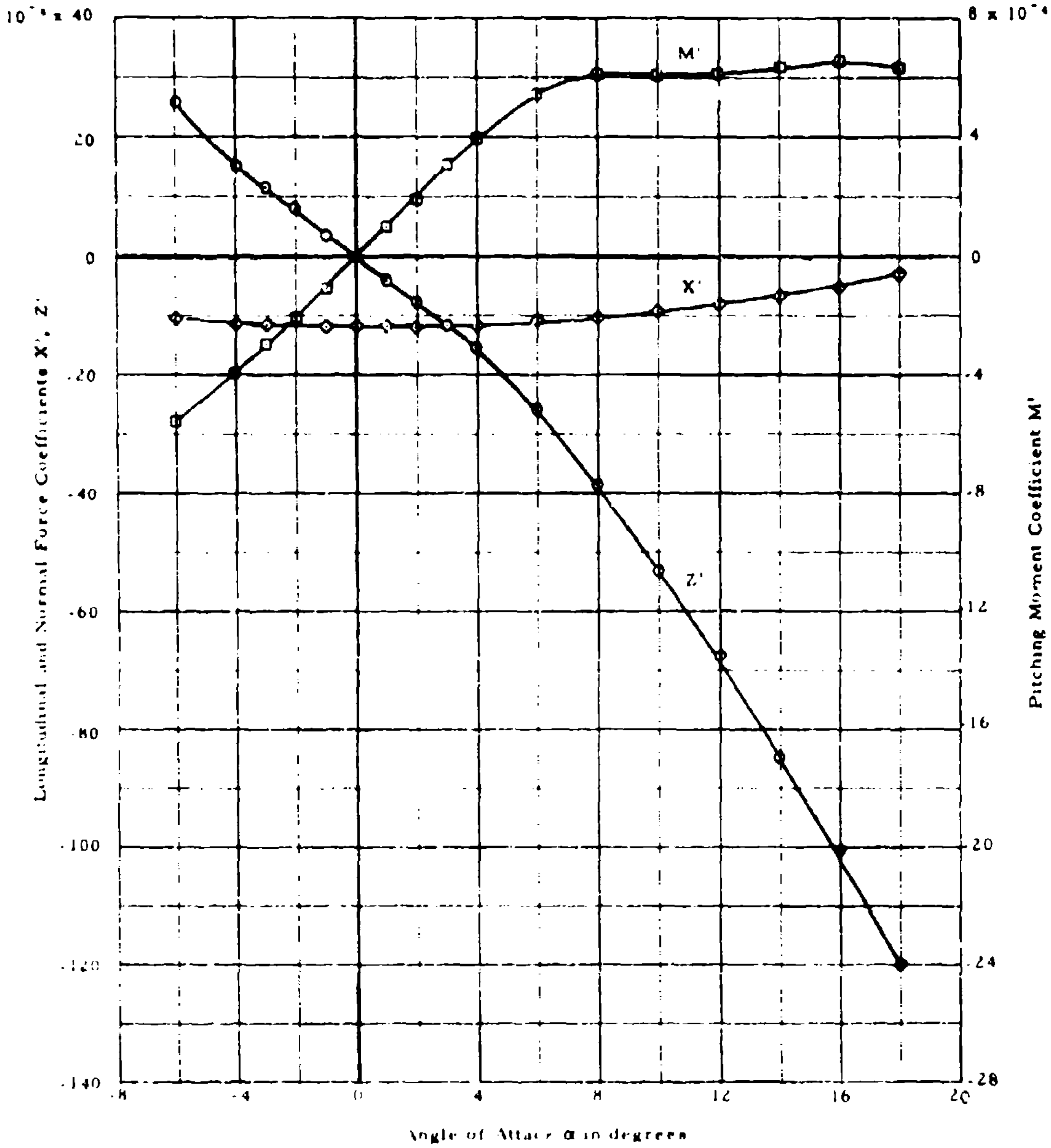


Figure 18 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 5C Sternplanes

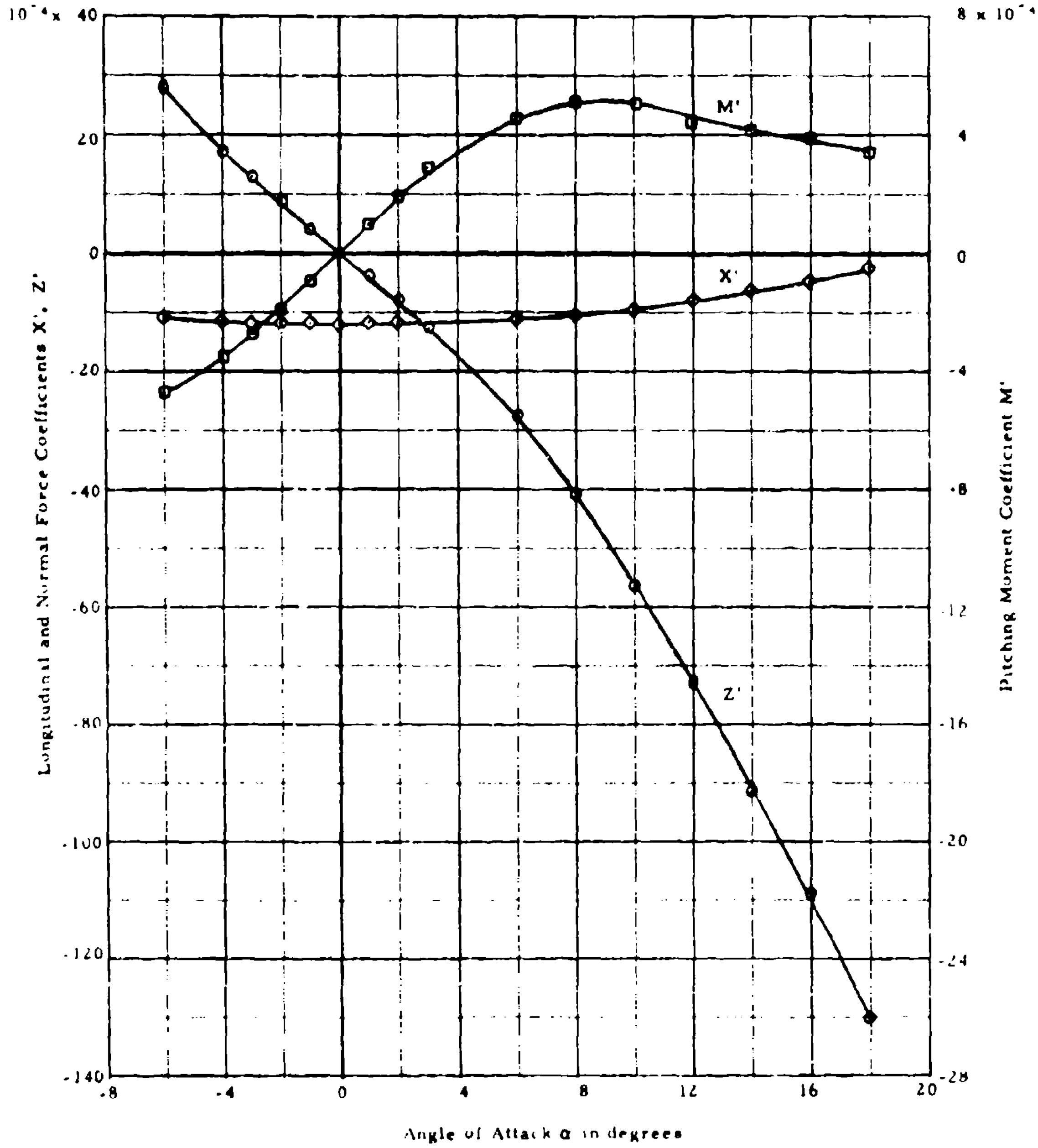


Figure 19 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 7C Sternplanes

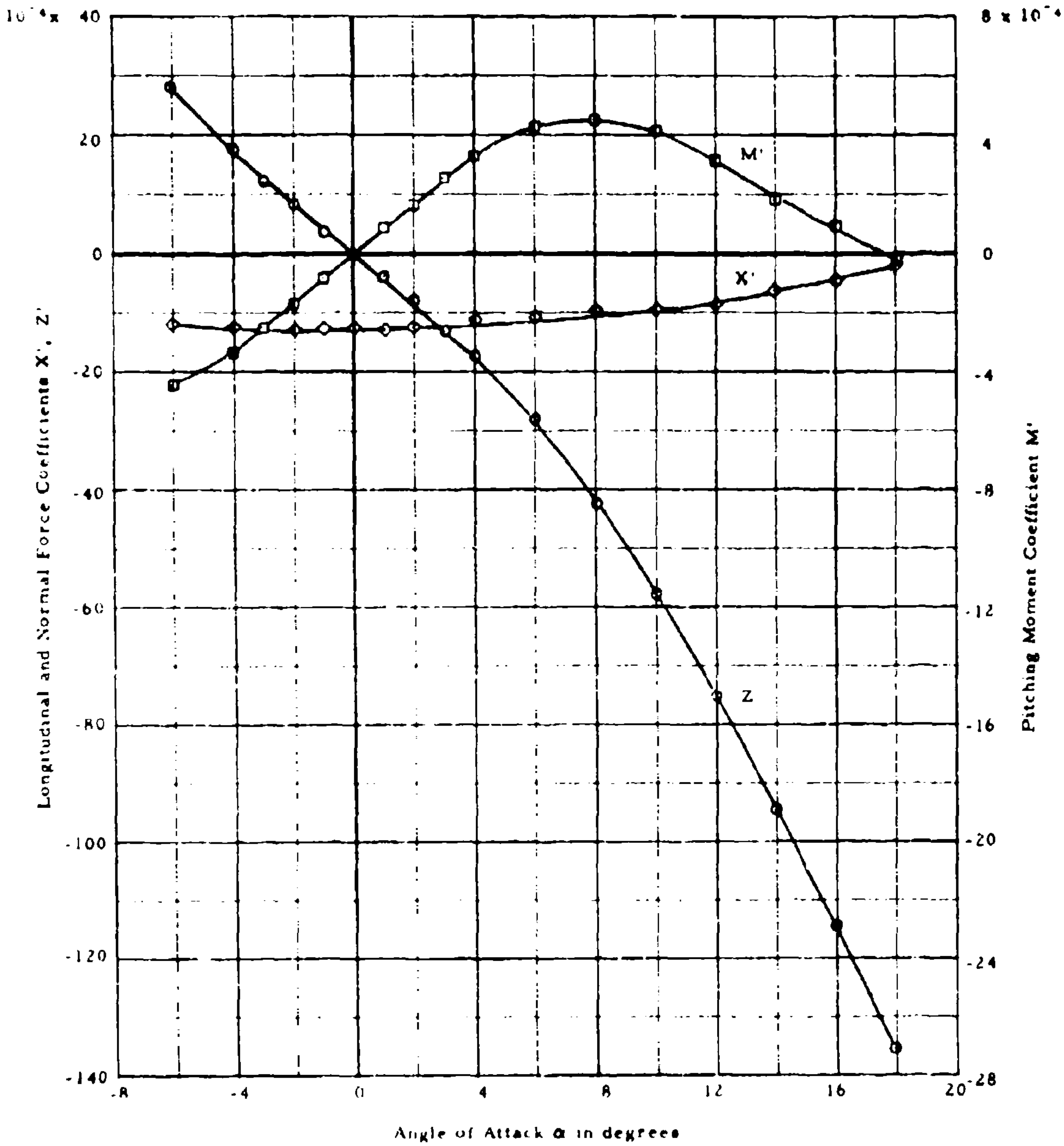


Figure 20 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 9C Sternplanes

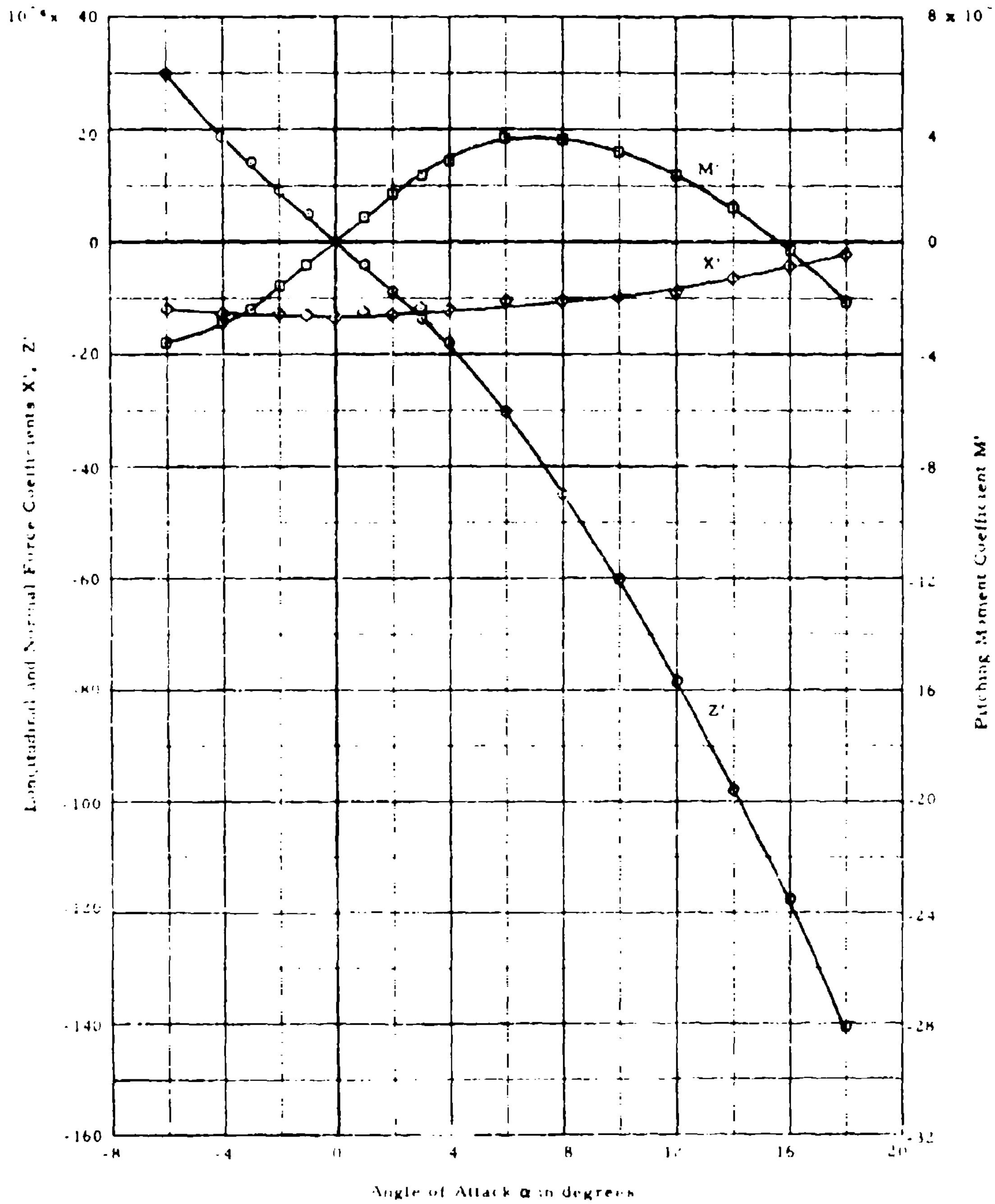


Figure 21 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 11C Sternplanes

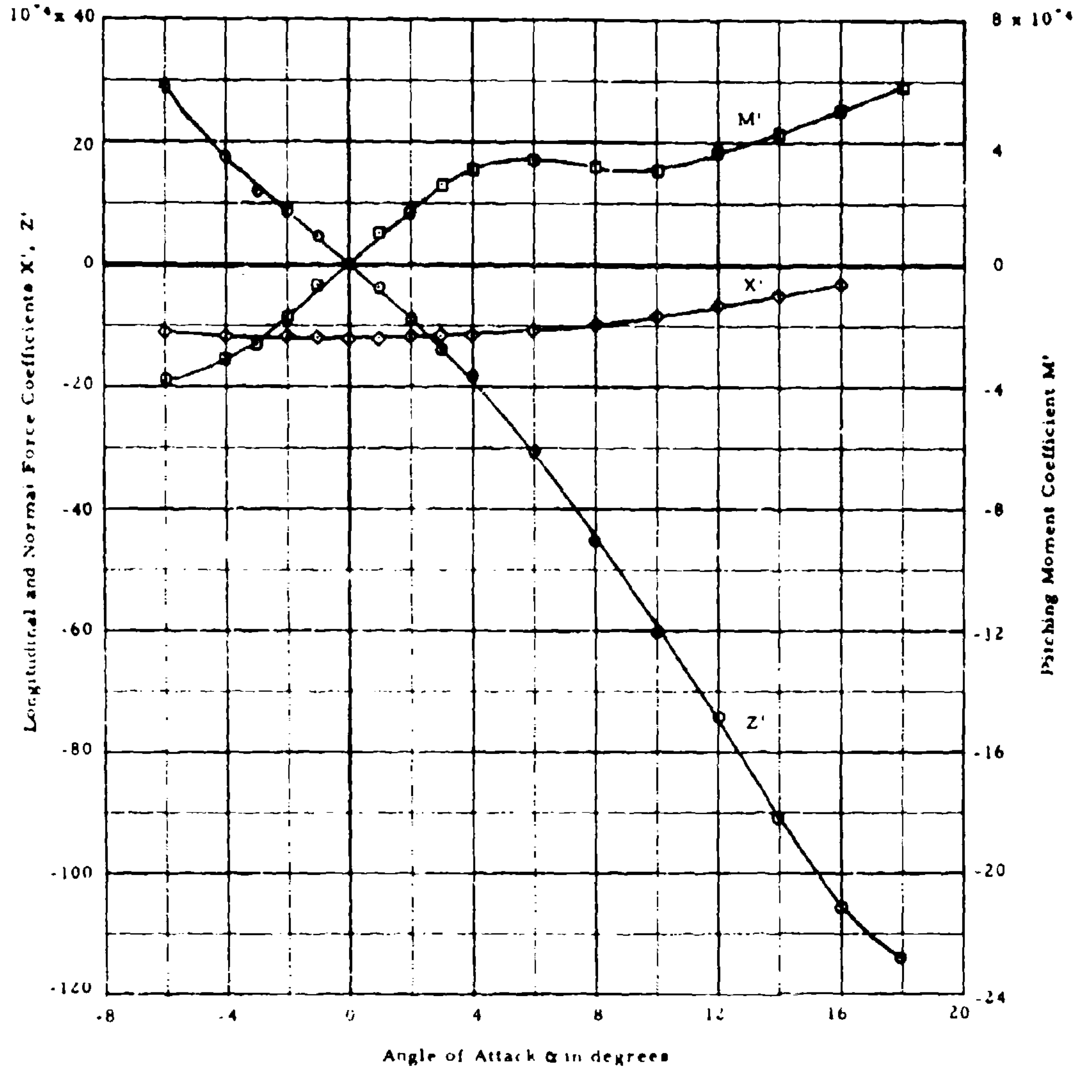


Figure 22 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 3D Sternplanes

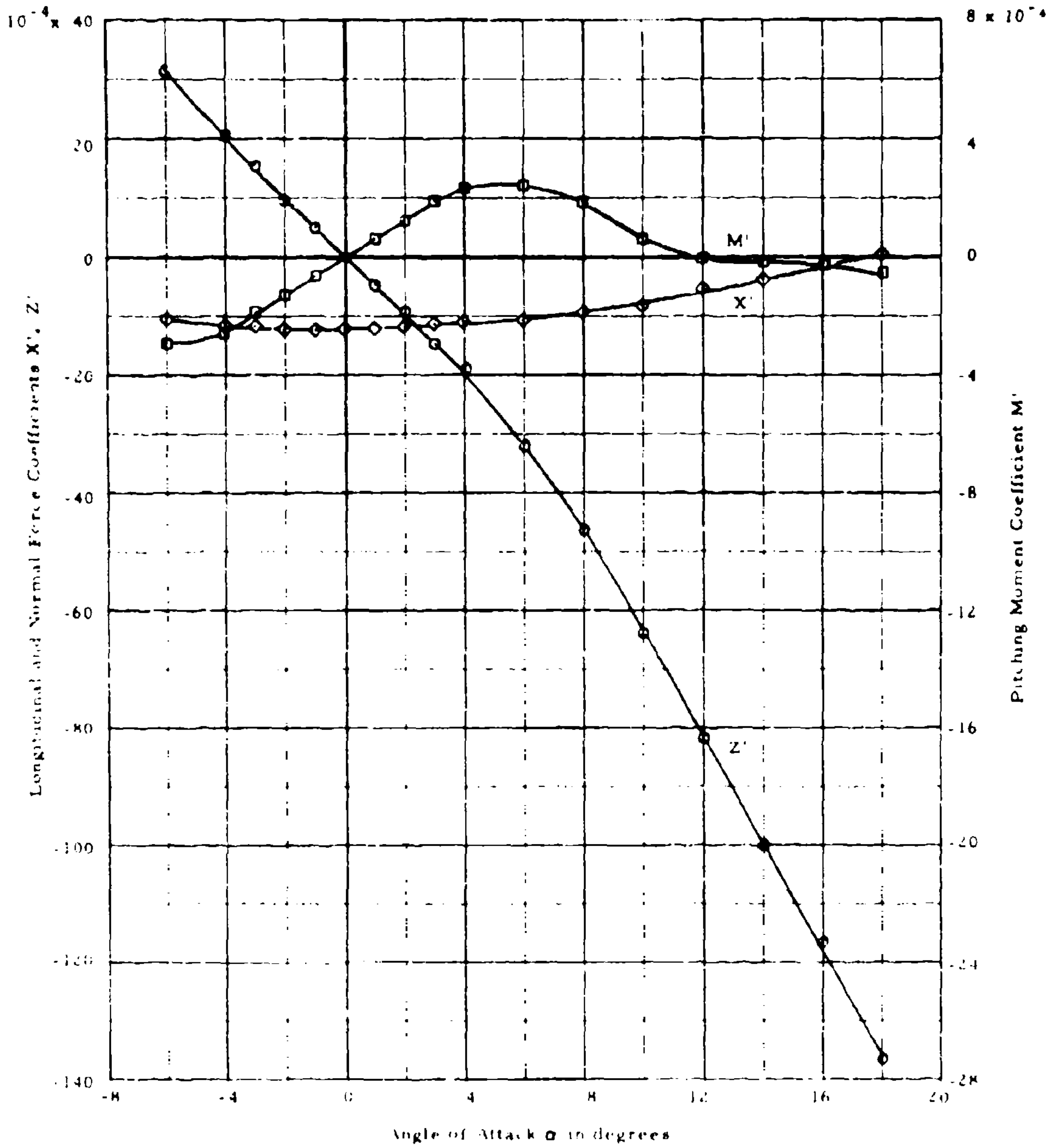


Figure 23 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 5D Sternplanes

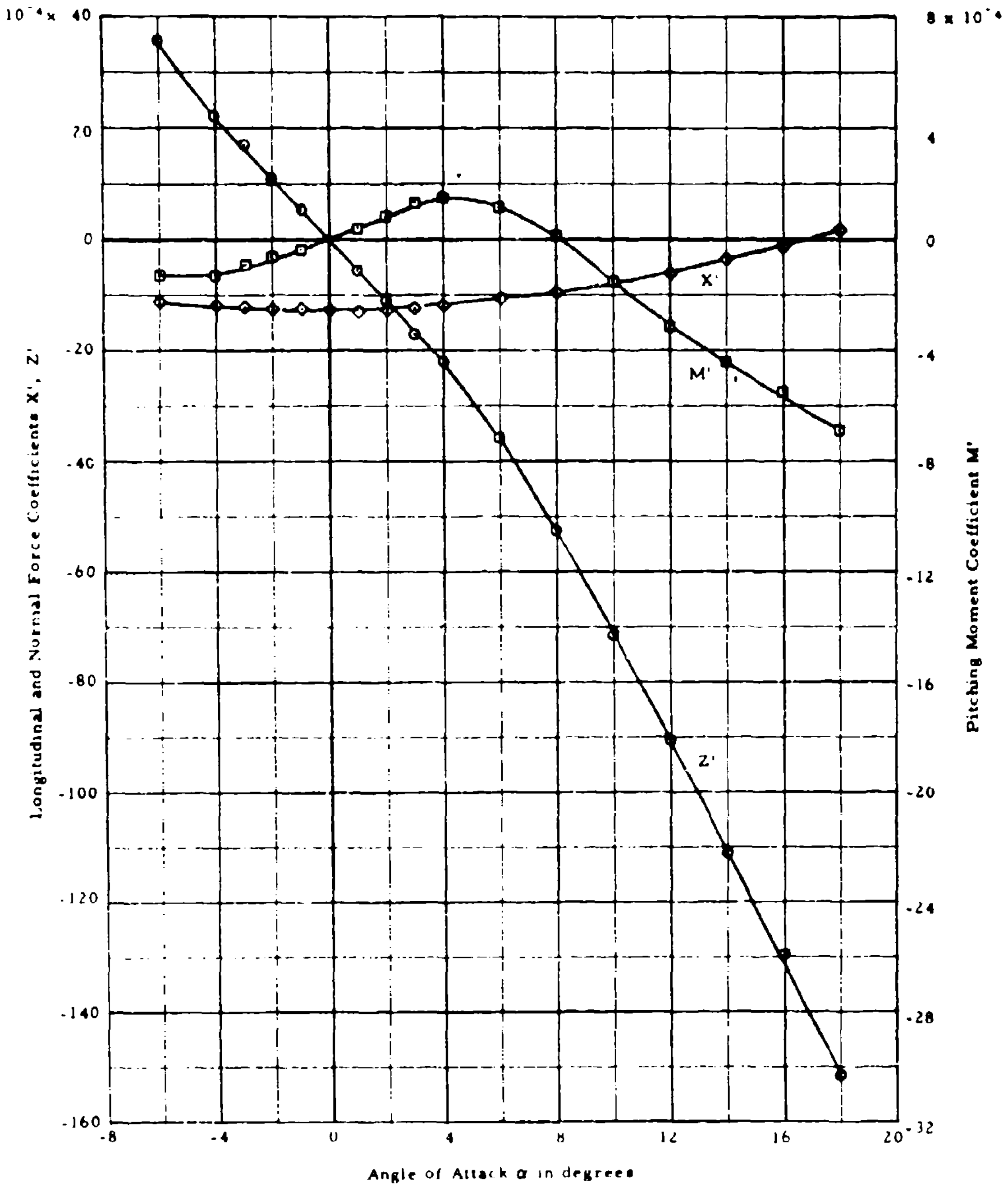


Figure 24 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 7D Sternplanes

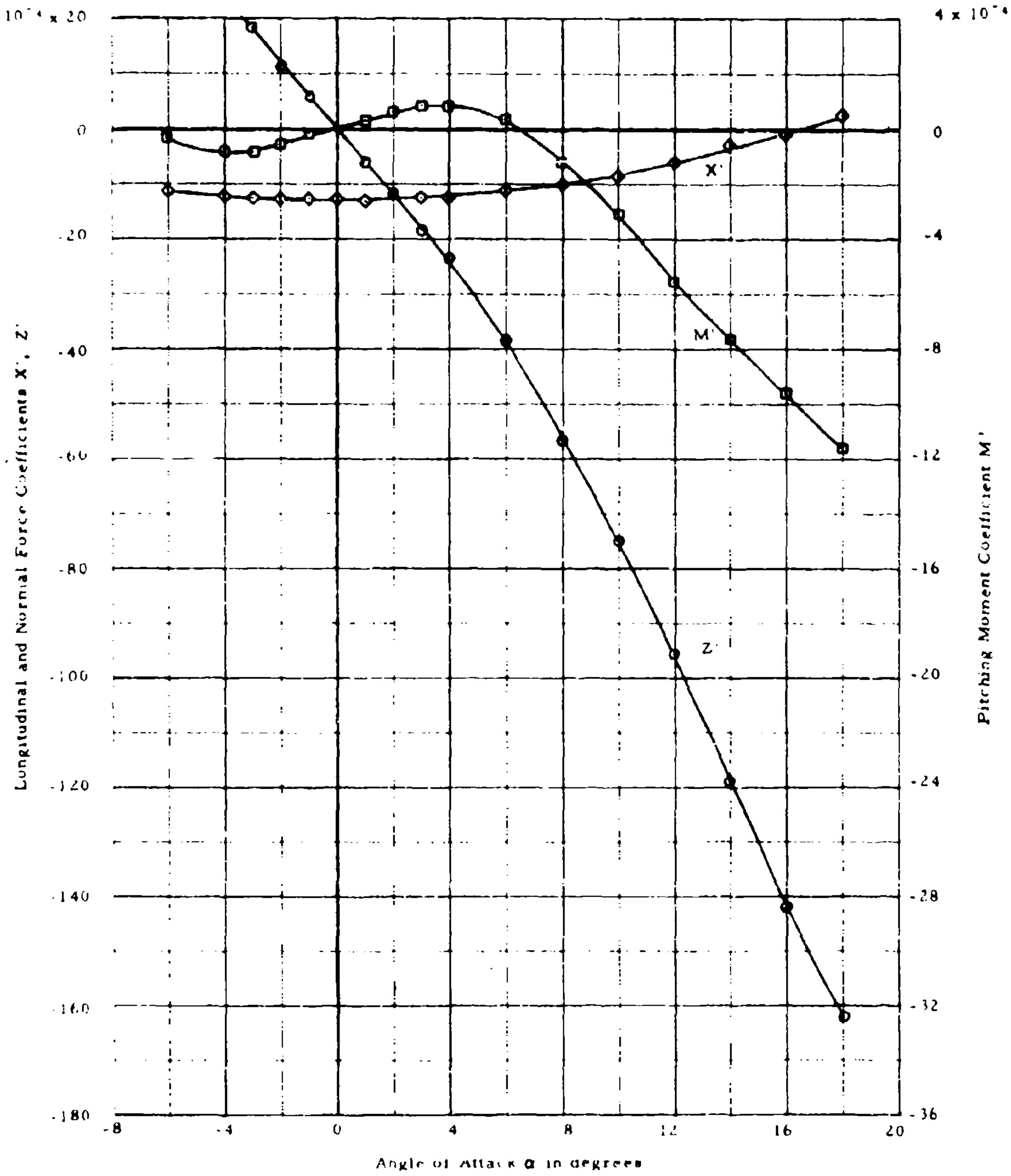


Figure 25 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 9D Sternplanes

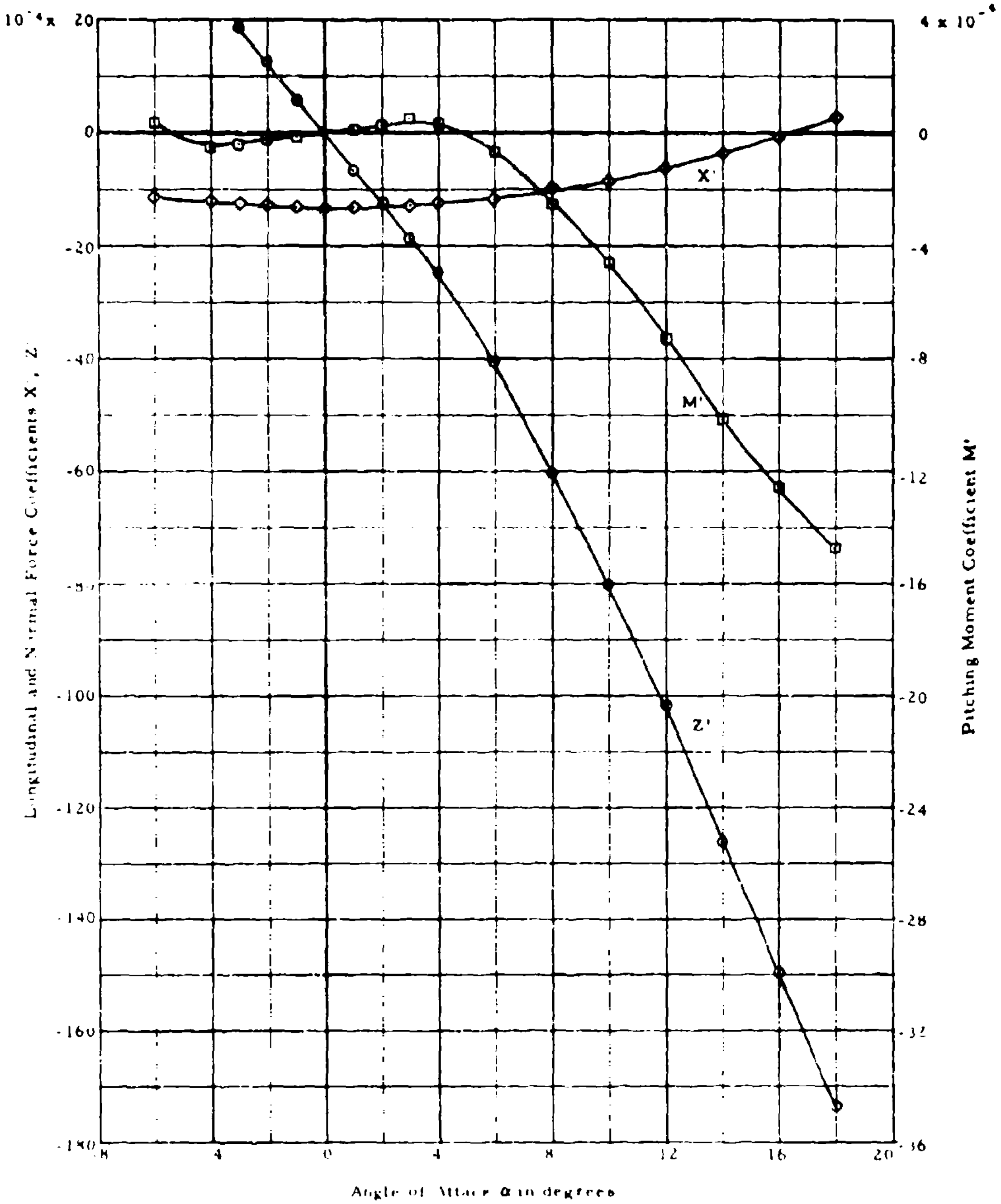


Figure 26 - Variation of Longitudinal and Normal Force and Pitching Moment Coefficients with Angle of Attack for Body with 11D Sternplanes

APPENDIX C

TABULATION OF LONGITUDINAL AND NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS DUE TO ANGLE OF ATTACK

TABLE 3 - TABULATION OF LONGITUDINAL AND NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS DUE TO ANGLE OF ATTACK

Bare Body

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-10.9	10.7	-12.29
-4	-10.7	6.5	-8.84
-3	-10.7	4.4	-6.62
-2	-10.7	2.6	-4.42
-1	-10.5	1.3	-2.23
0	-10.6	0	0
1	-10.8	-1.3	2.22
2	-10.7	-2.8	4.42
3	-10.7	-4.7	6.64
4	-10.6	-5.8	8.49
6	-10.6	-10.5	12.69
8	-10.5	-16.3	16.31
10	-10.6	-24.1	19.28
12	-10.4	-33.8	21.86
14	-10.0	-45.6	24.27
16	-9.6	-58.4	26.42
18	-8.5	-73.1	28.55

TABLE 3 (continued)

Body with Cruciform Stern 3A

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.6	13.3	-10.89
-4	-11.5	8.1	-7.65
-3	-11.3	5.8	-5.80
-2	-11.5	4.0	-4.02
-1	-11.6	2.0	-1.99
0	-11.4	0	0
1	-11.5	-2.0	1.92
2	-11.5	-3.8	3.91
3	-11.4	-6.0	5.93
4	-11.2	-7.9	7.44
6	-11.2	-13.9	10.94
8	-11.2	-21.9	13.74
10	-10.8	-31.4	15.81
12	-10.4	-45.0	17.67
14	-9.9	-56.2	19.32
15	-9.1	-69.8	20.68
18	-9.9	-82.0	22.48

Body with Cruciform Stern 5A

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.3	14.2	-10.68
-4	-11.3	8.4	-7.51
-3	-11.2	6.1	-5.68
-2	-11.3	4.1	-3.84
-1	-11.2	2.3	-1.89
0	-11.8	0	0
1	-11.6	-2.0	1.87
2	-11.5	-4.0	3.73
3	-11.7	-6.2	5.73
4	-11.6	-8.2	7.27
6	-11.4	-14.6	10.66
8	-11.1	-22.7	13.23
10	-11.1	-32.4	15.27
12	-10.4	-44.9	16.65
14	-9.7	-59.3	18.03
16	-8.9	-74.2	19.01
18	-7.8	-89.0	19.91

TABLE 3 (continued)

Body with Cruciform Stern 7A

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.2	14.8	-10.63
-4	-11.0	8.6	-7.45
-3	-11.4	6.1	-5.71
-2	-11.4	4.1	-3.87
-1	-11.4	1.6	-1.90
0	-11.2	0	0
1	-11.2	-2.2	1.90
2	-11.2	-4.2	3.87
3	-11.2	-6.4	5.93
4	-11.1	-8.4	7.40
6	-10.7	-14.9	10.80
8	-10.7	-23.9	13.44
10	-10.5	-33.9	15.41
12	-10.0	-46.5	16.89
14	-9.5	-60.6	18.49
16	-8.8	-76.4	19.62
18	-7.3	-94.3	20.87

Body with Cruciform Stern 9A

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.7	15.1	-10.35
-4	-11.7	8.7	-7.27
-3	-11.7	6.4	-5.53
-2	-11.8	4.2	-3.78
-1	-11.7	2.3	-1.86
0	-12.1	0	0
1	-12.0	-2.3	1.88
2	-11.9	-4.3	3.67
3	-11.8	-6.7	5.62
4	-11.9	-8.9	7.07
6	-11.7	-15.2	10.31
8	-11.5	-24.0	12.67
10	-11.3	-34.5	14.35
12	-10.8	-47.7	15.82
14	-10.2	-62.0	16.87
16	-9.5	-77.2	17.63
18	-8.3	-95.3	18.18

TABLE 3 (continued)

Body with Cruciform Stern 11A

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-12.0	14.7	-10.56
-4	-12.0	8.7	-7.41
-3	-11.9	6.4	-5.56
-2	-12.0	4.4	-3.81
-1	-11.9	2.2	-1.87
0	-12.3	0	0
1	-12.2	-2.2	1.83
2	-12.3	-4.3	3.80
3	-12.3	-6.5	5.78
4	-12.3	-8.6	7.25
6	-12.2	-15.1	10.48
8	-12.0	-23.9	12.96
10	-11.9	-34.3	14.75
12	-11.5	-47.3	16.11
14	-11.0	-62.6	17.11
16	-10.4	-76.8	17.56
18	-9.4	-94.6	17.97

Body with Cruciform Stern 3B

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-10.1	17.2	-8.82
-4	-11.4	11.0	-6.12
-3	-11.4	7.8	-4.72
-2	-11.4	5.2	-3.15
-1	-11.4	2.7	-1.64
0	-11.4	0	0
1	-11.6	-2.6	1.61
2	-11.6	-5.3	3.19
3	-11.4	-7.9	4.83
4	-11.3	-10.6	6.09
6	-11.1	-18.0	8.59
8	-10.7	-27.9	10.44
10	-10.0	-38.4	12.03
12	-9.4	-50.2	13.39
14	-8.4	-64.4	14.71
16	-7.5	-79.6	15.66
18	-8.2	-92.8	16.59

TABLE 3 (continued)

Body with Cruciform Stern 5B

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-3}

α Deg	X'	Z'	M'
-6	-10.7	20.3	-7.92
-4	-10.9	12.1	-5.77
-3	-	-	-
-2	-10.8	5.8	-2.84
-1	-11.0	2.7	-1.40
0	-11.1	0	0
1	-11.2	-2.9	1.39
2	-11.2	-5.7	2.93
3	-11.1	-9.1	4.51
4	-11.1	-11.9	5.59
6	-10.8	-20.1	8.01
8	-10.3	-30.3	9.55
10	-9.5	-42.2	10.42
12	-8.9	-56.5	11.16
14	-7.8	-71.4	11.98
16	-6.4	-87.3	12.53
18	-4.5	-105.2	13.00

Body with Cruciform Stern 7B

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.3	20.4	-7.42
-4	-11.9	12.8	-5.32
-3	-11.7	9.7	-4.15
-2	-11.5	6.3	-2.72
-1	-11.6	3.1	-1.24
0	-11.7	0	0
1	-11.5	-3.2	1.24
2	-11.5	-6.0	2.85
3	-11.2	-9.8	4.16
4	-11.3	-12.2	5.31
6	-11.0	-20.8	7.39
8	-10.7	-31.3	8.86
10	-10.1	-43.5	9.95
12	-9.4	-58.2	10.45
14	-8.4	-74.7	10.68
16	-6.9	-90.5	10.82
18	-5.2	-109.0	10.70

TABLE 3 (continued)

Body with Cruciform Stern 9B

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.4	21.4	-7.14
-4	-11.8	12.9	-5.08
-3	-	-	-
-2	-12.1	6.0	-2.64
-1	-12.1	2.9	-1.33
0	-11.8	0	0
1	-11.8	-2.9	1.37
2	-11.8	-6.3	2.65
3	-11.7	-9.4	3.94
4	-11.7	-13.0	5.07
6	-11.4	-22.2	7.14
8	-10.9	-33.1	8.38
10	-10.3	-45.9	9.23
12	-9.6	-61.1	9.61
14	-8.7	-78.3	9.67
16	-7.1	-94.7	9.55
18	-5.4	-113.7	9.26

Body with Cruciform Stern 11B

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.8	21.0	-7.08
-4	-12.1	12.5	-5.19
-3	-	-	-
-2	-12.1	6.5	-2.71
-1	-12.2	3.1	-1.31
0	-12.2	0	0
1	-12.1	-4.0	1.39
2	-12.1	-6.5	2.70
3	-	-	-
4	-12.0	-13.4	5.18
6	-11.3	-21.9	7.07
8	-10.9	-33.8	8.12
10	-10.4	-46.8	8.76
12	-9.7	-62.5	8.78
14	-8.6	-80.6	8.75
16	-7.2	-99.8	8.14
18	-5.7	-118.1	7.72

TABLE 3 (continued)

Body with Cruciform Stern 3C

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-10.7	22.7	-6.46
-4	-11.0	13.5	-4.84
-3	-11.2	10.3	-3.69
-2	-11.3	7.1	[illegible]
-1	-11.3	3.1	-1.28
0	-11.3	0	0
1	-11.8	-3.4	1.25
2	-11.6	-7.0	2.54
3	-11.7	-10.3	3.84
4	[illegible]	-13.5	4.85
6	-10.1	-22.5	6.45
8	-10.6	-34.7	7.44
10	- 9.6	-46.9	8.24
12	- 8.2	-61.0	9.05
14	- 6.6	-76.4	9.85
16	- 5.5	-91.3	10.55
18	- 3.6	-107.5	11.32

Body with Cruciform Stern 5C

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-10.8	25.9	-5.46
-4	-11.6	15.3	-3.95
-3	-11.8	11.5	-3.01
-2	-11.7	7.8	-2.10
-1	-12.1	3.5	-1.09
0	-12.1	0	0
1	-11.9	-4.3	0.99
2	-12.1	-7.9	1.89
3	-11.3	-11.8	3.06
4	-11.7	-15.4	3.97
6	-10.9	-26.0	5.43
8	-10.3	-38.6	6.09
10	- 9.2	-53.1	6.07
12	- 8.1	-67.6	6.15
14	- 6.8	-84.7	6.37
16	- 5.2	-100.4	6.59
18	- 2.7	-120.0	6.34

TABLE 3 (continued)

Body with Cruciform Stern 7C

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.3	27.8	-4.74
-4	-11.8	17.0	-3.56
-3	-12.1	12.8	-2.75
-2	-12.1	8.5	-1.91
-1	-12.0	4.1	-0.96
0	-12.2	0	0
1	-12.0	-4.0	0.97
2	-12.0	-8.3	1.90
3	-11.7	-12.9	2.87
4	-	-	-
6	-11.2	-27.9	4.59
8	-10.4	-40.9	5.12
10	-9.4	-56.4	5.01
12	-8.0	-72.9	4.41
14	-6.4	-91.6	4.17
16	-4.7	-108.9	3.98
18	-2.6	-130.2	3.42

Body with Cruciform Stern 9C

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.8	28.1	-4.45
-4	-12.4	17.4	-3.36
-3	-12.2	12.2	-2.53
-2	-12.7	8.2	-1.68
-1	-12.9	3.6	-0.83
0	-12.5	0	0
1	-12.9	-4.1	0.84
2	-12.5	-7.9	1.66
3	-12.1	-13.3	2.54
4	-11.2	-17.5	3.27
6	-10.8	-28.3	4.26
8	-9.6	-42.5	4.50
10	-9.4	-58.0	4.11
12	-8.5	-75.3	3.09
14	-6.2	-94.8	1.82
16	-4.4	-114.7	0.92
18	-2.2	-135.6	-0.21

TABLE 3 (continued)

Body with Cruciform Stern 11C

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-12.0	29.9	-3.63
-4	-12.7	18.4	-2.87
-3	-12.4	14.0	-2.45
-2	-12.9	9.1	-1.60
-1	-13.3	4.9	-0.85
0	-13.6	0	0
1	-12.5	-4.0	0.85
2	-13.2	-8.8	1.68
3	-11.8	-13.8	2.39
4	-12.3	-17.9	2.84
6	-10.4	-30.2	3.68
8	-10.5	-45.0	3.67
10	-9.7	-60.2	3.18
12	-8.7	-78.4	2.40
14	-6.5	-97.9	1.23
16	-4.2	-117.7	-0.31
18	-2.2	-140.7	-2.08

Body with Cruciform Stern 3D

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.1	28.7	-3.81
-4	-11.7	17.5	-3.14
-3	-11.8	12.1	-2.60
-2	-12.0	8.8	-1.71
-1	-12.1	4.5	-0.68
0	-12.2	0	0
1	-12.2	-3.9	1.02
2	-11.9	-8.9	1.73
3	-11.7	-14.0	2.59
4	-11.5	-18.0	3.12
6	-10.8	-30.4	3.43
8	-9.7	-45.3	3.26
10	-8.4	-59.9	3.08
12	-6.8	-74.2	3.70
14	-5.0	-90.8	4.33
16	-3.2	-105.5	5.05
18	-	-113.8	5.85

TABLE 3 (continued)

Body with Cruciform Stern 5D

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-10.7	31.5	-2.95
-4	-11.5	20.4	-2.59
-3	-11.8	15.4	-1.87
-2	-12.2	9.8	-1.29
-1	-12.5	4.9	-0.67
0	-12.3	0	0
1	-12.3	-4.9	0.59
2	-12.0	-9.4	1.21
3	-11.4	-15.0	1.88
4	-11.2	-19.0	2.28
6	-10.6	-32.0	2.42
8	- 9.3	-46.5	1.84
10	- 8.1	-64.2	0.63
12	- 5.6	-81.9	-0.04
14	- 3.8	-100.2	-0.08
16	- 1.8	-116.8	-0.22
18	0.5	-136.9	-0.58

Body with Cruciform Stern 7D

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.3	35.7	-1.31
-4	-11.9	22.3	-1.31
-3	-12.2	17.0	-0.95
-2	-12.4	10.9	-0.64
-1	-12.6	5.3	-0.41
0	-12.7	0	0
1	-12.7	-5.9	0.40
2	-12.5	-11.0	0.80
3	-12.4	-17.3	1.34
4	-12.0	-22.0	1.47
6	-10.7	-35.8	1.16
8	- 9.6	-52.4	0.09
10	- 8.2	-71.4	-1.53
12	- 6.2	-90.4	-3.22
14	- 3.6	-111.0	-4.43
16	- 1.2	-129.6	-5.51
18	1.9	-151.7	-6.91

TABLE 3 (continued)

Body with Cruciform Stern 9D

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.2	38.7	-0.36
-4	-12.2	25.1	-0.85
-3	-12.5	18.3	-0.85
-2	-12.7	11.5	-0.58
-1	-12.7	6.0	-0.18
0	-12.9	0	0
1	-13.0	-6.0	0.27
2	-12.6	-11.9	0.63
3	-12.5	-18.3	0.85
4	-12.4	-23.5	0.80
6	-11.2	-38.5	0.36
8	-10.0	-56.4	-1.20
10	-8.4	-74.7	-3.04
12	-6.1	-95.7	-5.59
14	-2.9	-118.8	-7.61
16	-0.8	-142.1	-9.62
18	2.6	-162.2	-11.59

Body with Cruciform Stern 11D

VALUES OF ALL COEFFICIENTS MUST BE MULTIPLIED BY 10^{-4}

α Deg	X'	Z'	M'
-6	-11.5	40.4	0.42
-4	-12.2	25.8	-0.52
-3	-12.5	18.7	-0.43
-2	-12.8	12.4	-0.25
-1	-13.2	5.7	-0.25
0	-13.4	0	0
1	-13.1	-6.8	0.10
2	-13.0	-12.4	0.24
3	-12.8	-18.7	0.51
4	-12.5	-24.7	0.33
6	-11.7	-40.6	-0.66
8	-9.9	-60.3	-2.49
10	-8.6	-80.0	-4.59
12	-6.2	-101.7	-7.28
14	-3.4	-126.1	-10.19
16	-0.6	-149.6	-12.56
18	3.0	-173.5	-14.75

APPENDIX D

STATIC STABILITY DERIVATIVES, INCREMENTAL DERIVATIVES AND FREE-STREAM LIFT-CURVE SLOPES FOR STERN CONFIGURATION SERIES

TABLE 4 - STATIC STABILITY DERIVATIVES, INCREMENTAL DERIVATIVES, AND FREE-STREAM LIFT-CURVE SLOPES FOR STERN CONFIGURATION SERIES

Sternplane Configuration	Z_w'	M_w'	$\Delta Z_w'$	$\Delta M_w'$	$C_{Z\alpha}$	$C_{L\alpha}$
3A	-0.01117	0.01117	-0.00315	-0.00145	1.223	3.502
5A	-0.01189	0.01072	-0.00387	-0.00190	1.049	2.944
7A	-0.01218	0.01060	-0.00416	-0.00202	0.866	2.509
9A	-0.01239	0.01061	-0.00437	-0.00201	0.739	2.169
11A	-0.01239	0.01061	-0.00437	-0.00201	0.622	1.903
3B	-0.01499	0.00906	-0.00697	-0.00356	1.815	3.754
5B	-0.01662	0.00825	-0.00860	-0.00437	1.616	3.277
7B	-0.01776	0.00770	-0.00974	-0.00492	1.432	2.883
9B	-0.01833	0.00759	-0.01031	-0.00503	1.244	2.558
11B	-0.01862	0.00768	-0.01060	-0.00494	1.085	2.287

TABLE 4 (continued)

Sternplane Configuration	Z_w'	M_w'	$\Delta Z_w'$	$\Delta M_w'$	$C_{Z\alpha}$	$C_{L\alpha}$
3C	-0.01933	0.00716	-0.01131	-0.00546	2.241	3.893
5C	-0.02199	0.00586	-0.01397	-0.00676	2.043	3.472
7C	-0.02396	0.00526	-0.01594	-0.00736	1.848	3.111
9C	-0.02500	0.00469	-0.01698	-0.00793	1.630	2.804
11C	-0.02560	0.00468	-0.01758	-0.00794	1.440	2.542
3D	-0.02498	0.00496	-0.01696	-0.00766	2.539	4.013
5D	-0.02840	0.00358	-0.02038	-0.00904	2.305	3.645
7D	-0.03137	0.00229	-0.02335	-0.01033	2.122	3.321
9D	-0.03438	0.00162	-0.02636	-0.01100	2.003	3.037
11D	-0.03572	0.00073	-0.02770	-0.01189	1.808	2.791

Notes: 1. Z_w' and M_w' for the bare body are -0.00802 and 0.01262 respectively.

2. $C_{L\alpha}$ is computed from Equation (1) using the effective aspect ratio of the planes extended through the body.

3. $C_{Z\alpha} = -\Delta Z_w' \dfrac{\ell^2}{2A}$

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